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COMPARATIVE COSTS OF EROSION AND SEDIMENT CONTROL CONSTRUCTION ACTIVITIES

Robert E. Thronson

Engineering-Science, Incorporated

Prepared for:

Environmental Protection Agency

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Berkeley, California

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Cost information on erosion and sediment control measures was developed for over 25 methods in current widespread use in both the humid Eastern and arid Western United States. Most of the data presented were developed for the Walnut Creek Basin in California and the Occoquan Creek Basin in Virginia, but the detailed cost estimates presented provide a basis for estimating local costs elsewhere for similar control methods using three principal cost elements: labor, equipment and materials. Soil losses were estimated by using the improved universal soil loss equation. The rainfall erosion index in the soil loss equation was intensively studied, and simplified procedures for its computation were developed and presented. Cost data were applied to theoretically-predicted soil losses in both of the selected watersheds to obtain comparative costs per cubic yard of soil retained for conservation measures, and similar costs for various sediment removal methods. Control effectiveness parameters and economic life of each method were used to determine comparable annual cost figures. A central conclusion of the study was that costs of preventing erosion are, in many instances, lower than the direct costs of removing sediments from downstream areas or from water supplied. ~~(Hotes - California)~~ (EPA)

-- *Erosion control, *Sediment control, *Comparative costs, *Construction costs, *Soil erosion, *Estimated costs, Erosion rates, Cost analysis, Rainfall intensity, Water pollution, Water pollution sources, Water clarification, Soil conservation, Dredging, Desilting, California, Virginia

--*Universal soil loss equation, Occoquan Creek Basin (Virginia), Walnut Creek basin (California), Rainfall erodibility Index, Debris basins

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Engineering-Science, Inc., Berkeley, CA

COMPARATIVE COSTS OF EROSION AND SEDIMENT CONTROL, CONSTRUCTION ACTIVITIES

Project Officer

Robert E. Thronson

Prepared for

U. S. ENVIRONMENTAL PROTECTION AGENCY

Office of Water Program Operations
Water Quality and Non-Point Source Control Division
Washington, D. C. 20460

JULY 1973

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ABSTRACT

Cost information on erosion and sediment control measures was assembled, evaluated and documented for more than 25 methods in current wide-spread use in both the humid Eastern and arid Western United States. Elemental data for cost parameters were obtained for each method through extensive investigation of erosion and sediment control contracts, estimates provided by contractor estimators, furnished job costs, equipment and supply catalogues, and other sources. A wide range of costs was found between one location and another; and conditions affecting these variations were also determined. Most of the data presented were obtained from two specific watersheds: Walnut Creek Watershed in Central California and the Occoquan Watershed in Virginia. Relevant data from areas outside these watersheds were utilized, where applicable.

Sediment removal cost estimates were made for typical situations where unwanted sediment, which had been transported from construction sites into adjacent areas and deposited, requires removal. The basis for making these cost estimates generally was similar to those used in preparing estimates for costs of control.

Theoretical soil losses were determined by using the improved universal soil loss equation and the graphic methods for evaluation of factors used therein. The hydrologic parameter for the soil loss equation was intensively studied and simplified procedures for its computation were developed and presented. Cost data were applied to theoretically predicted soil losses for both of the selected climatologically different basins in order to obtain costs per cubic yard (cy) of soil retained for conservation measures and costs per cy of sediment removal with various methods.

Control effectiveness parameters and the duration of effectiveness of each method were used to determine comparable annual cost figures. A central conclusion of the study is that each particular location offers a unique soil loss potential, erosion control costs and corresponding sediment removal penalties. Costs of preventing the erosion and transportation of sediments are, in many instances, lower than the cost of removing the same quantities of sediments from downstream areas.

This report was submitted in fulfillment of the requirements of Contract Number 68-01-0755 under the sponsorship of the Office of Water Program Operations, U.S. Environmental Protection Agency.

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LIST OF ABBREVIATIONS

The abbreviations, signs, and symbols used in this report are standard and conform to those appearing in the Government Printing Style Manual. In each instance, the first time an abbreviation, sign, or symbol is used it appears parenthetically after the word or term for which it stands or describes.

ARS	Agricultural Research Service, USDA
AWWA	American Water Works Association
CA	California
ENR	Engineering News-Record Magazine
EPA	Environmental Protection Agency
ES	Engineering-Science, Inc.
LACFCD	Los Angeles County Flood Control District
SCS	Soil Conservation Service, USDA
TP	Technical Paper
TR	Technical Release
USDA	United States Department of Agriculture
USWB	United States Weather Bureau
VA	Virginia

Units and Symbols

ac	acre
bbl	barrel
bf	board feet
bm	board measure
cf	cubic feet
cfs	cubic feet per second
cwt	hundredweight
cy	cubic yard
ea	each
ft	feet
sq. ft	square feet
hr	hour
lbs	pounds
lf	lineal feet
l	liter
m-days	man days
mg	milligram
mgd	million gallons per day
m-hr	man hour
OH	Overhead
P	Profit
S4S	Square four Sides
sf	square feet (Tabulations Only)
sy	square yard
yr	year
@	at
%	percent
¢	cents (U. S.)
$	dollars (U. S.)
'	foot (Tabulations Only)
"	inch (Tabluations Only)
/	per
°, '	degree, minute
Δ	change

SECTION I

INTRODUCTION

1. THE PROBLEM

Natural erosion processes inevitably are accelerated when existing protective cover is removed before or during construction of land development, highway, or airfield facilities. Increased exposure of the soil mantle to the full kinetic energy of falling rain, hail, and overland and channelized flow, plus the dynamic mechanical action of men and machines as they move over the site, cause increased movement and loss of soil particles. While this erosion of soil frequently causes on-site construction problems, it is even more common for the sediment removed to create many undesirable conditions in downstream areas. Furthermore, loss of the soil from the site is, in many instances, a loss of a valuable natural resource.

Erosion of still-unpaved streets, embankments, and building foundations are not uncommon sights in the expanding urban areas of America today. Deposition of the eroded sediments in storm sewers, culverts, drains, and waterways decreases their capacities or completely clogs them, which in turn results in flooding of adjacent and downstream lands. Valuable reservoir storage is lost and domestic water supplies become turbid, or water filters clogged, following storms. Beautiful lakes become dirty and unattractive bodies of water for long periods of time, with adverse effects on water-related recreation. Numerous new-home owners sometimes awake to find their yards or streets or even their homes filled with mud.

Most of these adverse results from man's construction activities can be reduced, and, in many instances, eliminated by use of both structural and non-structural measures of various types, properly utilized, at the appropriate time.

Selection of the proper measures to use in any specific situation, however, requires the availability of both technical and comparative cost information on the various methods.

2. PURPOSE OF THIS STUDY

"Guidelines for Erosion and Sediment Control Planning and Implementation" was published by EPA in August 1972 (Reference 120), and "An Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization" was published by the Department of the Interior in 1972 (Reference 26). The first publication summarizes most of the available structural and vegetative control methods which can be used. It can be used both by the layman and the conservation specialist. The second provides extensive analyses of erosion control costs in selected urbanizing watersheds in Maryland, near Washington, D. C., and estimates of the economic values of damages resulting from erosion in those areas.

The purpose of the present study is to extend the work and data of the previous reports and, more specifically, to provide reliable information on: (1) The cost of retaining sediments on construction sites per cubic yard (cy) of material retained. (2) The cost of correcting damages resulting from erosion and sediment deposition on the site and in downstream areas per cy of material removed.

3. SCOPE OF STUDY

In this study data have been obtained for two different climatic areas in the United States; one being in the relatively semi-arid area of California, primarily Northern California, and the other being located in Virginia, which is in the more humid eastern part of the nation. Rainfall distribution over the year is quite different in the two areas, the soils are not the same, labor costs differ, and the extent of erosion control practiced on construction sites generally is much more limited in the Walnut Creek Basin as compared to the Occoquan Basin. The types of control measures available or used, however, are essentially the same.

Areas with significant differences in climatic parameters were selected deliberately, not only to provide a broader data base, but also to help focus on the important parameters influencing amounts, times, and rates of soil erosion on and near construction sites, so that these parameters could then be used in other climatic areas of the United States in planning, designing, and evaluating erosion control measures and practices. Several such parameters were identified, and illustrative examples are given of their application in the study areas, together with discussions of how the same approaches can be used in other regions. Limitations of the methods are also stated.

It was realized at the beginning that a simple presentation of unit costs per cy of sediment retained or removed could be misleading if the conditions to which it applies are not fully specified. Labor, material, and equipment costs vary from place to place. Furthermore, present costs can change, and the historic trend is that these costs increase, at different rates. In addition, "costs" depend upon accounting methods and the type of organization performing the work. The same work can have a different "cost" if reported by a home owner who has largely performed the work himself, by a city or county public works department, or by a contractor for a client, even though the equipment, material and manpower used were substantially identical. This report therefore presents most costs of erosion control practices and sediment removal work in terms of the three elements: labor, equipment, and materials. To further aid in understanding the mark-up of construction costs for these measures, allowances for overhead and profit are identified, so that contractors and government agencies can more readily use the data in developing or comparing their own estimates, based on local conditions.

Where appropriate, the effectiveness of the various methods are presented, although only qualitative information is available in some instances. Quantitative evaluations of erosion control practices are based on estimates of soil loss with and without the practice, as measured by the universal soil loss equation (Reference 136). Its applicability to the western United States has not yet been verified, because of differences in rainfall intensity patterns in the West compared to the eastern United States where all the experimental data was obtained. Nevertheless, analyses made during this study and summarized herein give additional evidence that the equation is applicable to the western as well as to the eastern United States, and to many other areas of the world. Examples of and instructions for its use are presented.

SECTION II

SUMMARY AND CONCLUSIONS

Costs of controlling sediments on site or removing them from downstream areas vary widely, even in a single region, due to differences in objectives, in the materials and practices used, and the relative effectiveness and durability of the practice applied or feature installed.

Unit costs of erosion prevention measures or sediment removal methods obtained in one area cannot be transferred to other areas for the purpose of estimating total costs without proper adjustments for climate, soils, terrain, materials, labor, equipment, and degree of performance desired.

The detailed cost estimates presented in this report for over 25 measures, practices, and methods provide a reasonable basis for estimating local costs for similar control methods.

The hydromulching method of applying protective covering to disturbed soil surfaces has emerged as a most economical, effective and practical erosion control method. The unit cost of hydromulching ranges from less than $400 per acre for areas of 15 acres and over with a minimum of constraints, to as high as $900 per acre for areas of less than one acre.

The more costly methods of preventing sheet and rill erosion on sloping land surfaces, such as those using excelsior matting and jute netting, generally are more durable on the steeper slopes than the less expensive methods such as hydromulching. As these higher-cost methods usually are most applicable to places where the erosion potential is the greatest, they often are economically justified.

The annual erosion potential in the Occoquan Creek Basin in Eastern Virginia is estimated to be approximately five times as great as that in the Walnut Creek Basin in California. Furthermore, the erosion potential during the summer construction season in Virginia is at its peak, while the erosion potential in California is practically non-existent during the same period of time.

The universal soil loss equation is the best index presently available to predict relative soil loss due to sheet and rill erosion. It is most reliable for slopes under 20 percent. It should be recognized, however, that the equation is semi-empirical, does not necessarily yield precise absolute values of erosion, and is subject to further modification, or replacement, as the results of current and future research work and analyses become available. It is most valuable when interpreted by qualified users.

More field experiments and research data are needed regarding erosion on steep slopes to permit the application thereto of the universal soil loss equation, or the development of a better, more applicable equation.

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More research work is needed to develop quantitative data and comparisons of the actual "effectiveness" of most conservation measures. Effectiveness figures now available are based on the considered judgments and experience of experts in soil conservation work, and, while suitable for use until better data are obtained, need field confirmation to increase confidence in their validity.

Costs of preventing soil erosion and sediment runoff per unit of sediment retained, are less, in a great many instances, than the cost of later removing the silt from homes, streets, stream channels, estuaries, bays, or domestic water supplies.

Although more and more erosion-conscious construction specifications, together with increased labor and materials costs, have forced unit costs upward, new and continuing improvements in techniques have kept the rate of increase within reasonable limits.

BRIEF REVIEW OF STATE-OF-THE-ART, EROSION AND SEDIMENT CONTROL

1. INTRODUCTION

While the basic processes of sediment erosion, transport, and deposition are essentially the same from one place to another, the environment in which they take place is subject to continuously changing and increasingly complex stresses, most of which are induced by man. The need for knowledge in erosion and sediment control techniques is increasing. (Reference 2).

It is essential that erosion and sediment control problems be approached from the standpoints of judicial use of existing information and technical data, and continued search for and assessment of new and definitive techniques related to the problems. However, since the objective of this report is to collect facts on cost of erosion and sediment control and sediment removal, only a brief review of the state-of-the-art is presented herein. For detailed and exhaustive review of literature and state-of-the-art, the reader is referred to References 26 and 48. The draft copy of the state-of-the-art synthesis which was recently made available on "Erosion Control on Highway Construction Projects" produced by the National Cooperative Highway Research Program, Project 20-5 (dated January 1973), contains summary information on current erosion-control practices and refers to numerous articles on the subject. The selected list of references at the end of this report contains 140 additional sources of valuable information pertinent to this study.

2. EROSION

Much of the soil erosion research to date has been conducted for resolving agricultural problems, and directed towards unravelling the complexities of erosion phenomena from disturbed topsoils and subsoils. Most urban development projects, construction work sites, and major highway projects also involve exposed and disturbed soils which are readily amenable to natural erosive forces. Erosion of subsoils is becoming increasingly important becuase of changing design criteria and ever-increasing size of sub-divisions and other construction and highway projects. The time required for the construction of large projects has been increasing and consequently erosion problems during construction have become very real and extensive. (Reference 2).

Soil erosion is essentially the detachment and relocation of soil particles through the dynamic action of water or wind. This fact led early investigators of erosion phenomena to examine the inherent properties of various soils in an effort to develop an index to describe or quantify the erodibility of soils. Middleton's (Reference 63) dispersion ratio and erosion ratio, and Anderson's (Reference 3) surface aggregation ratio, while important technical contributions, are of little use today, as erosion indices because they reflect only the intrinsic properties of soil and do not consider physiographic and hydrometeorological factors. In 1947 Musgrave (Reference 68) attempted a quantitative evaluation of loss of soil by water erosion by also taking into consideration the slope and length of agricultural lands.

Refinements to the Musgrave equation and extensive field and laboratory investigations produced by 1958 an equation known as the universal soil loss equation, which currently is used by the U. S. Soil Conservation Service to estimate gross erosion from rainfall on farmlands east of the Rockies. This equation developed by Wischmeier, Smith, Uhland, and others, (References 131 through 137), includes parameters representing both the properties of soil and the external influences of rainfall, overland slope, land management practices, and surface cover conditions. Improvements have been and are being introduced to make the equation truly universal, so that it is applicable to both agricultural and non-agricultural land, and for short-term as well as for long-term conditions (References 61, 95, 105, 107).

More detailed information on the applicability and use of the universal soil loss equation is presented in Section VII.

3. SEDIMENT YIELD AND DELIVERY

Investigators of the erosion phonomenon recognized the close link between erosion and other sedimentation processes. Various empirical equations were developed for predicting sediment yield based on known or measureable watershed parameters (References 25, 27, 34, 64, 68, 74, 129 and 130). Musgrave's (Reference 68) early attempts at predicting sediment yield was further refined when the sediment delivery ratio was introduced to take into consideration that not all the gross amount of eroded material leaves the watershed. As the area of the watershed increases the amount leaving the watershed decreases (Reference 74). However, the sediment delivery ratio has proven to be a special characteristic of the watersheds studied and of the conditions during the period of study, and therefore, a multitude of equations have been developed (References 64, 74, 130).

4. METHODS OF EROSION AND SEDIMENT CONTROL

Erosion control methods fall basically into one of two broad categories. These are designated as vegetative and structural measures. In actual field practice a combination of methods, suitable to the particular site, are employed. Chemical mulches may be placed in a class by themselves. However, because they are usually applied to support and insure emergence of vegetation seeds, they are included in this report under vegetative measures.

A. Vegetative

Vegetative measures include perennial grasses and legumes; annual cover; trees, shrubs, and vines; and mulches (organic and inorganic) to support vegetation and protect soil. The recent development of hydromulching has gained a degree of success in applying grass seed mixed with wood fiber and water under pressure. Well-anchored vegetative mulch has proven to be an effective and least costly of all mulching materials in controlling erosion from denuded areas.

Commercial materials available for controlling erosion used in conjunction with or without vegetative treatment are many and varied. Chemical mulching products, which are designed to prevent erosion during rainstorms until vegetation takes hold, include: polyvinyl alcohol, a resin product, an elastromeric polymer emulsion, Curasol (Reference 41) and Landlock (Reference 60).

A large number of new chemical products are on the market and tests are being carried out by several agencies to determine their relative effectiveness (Reference 60).

B. Structural

Structural measures include: small flood control dams, dikes and levees; stream channel improvements and bank stabilization works; sediment basins and outfall structures; terraces, diversion structures and channels; grassed waterways and outlets; grade stabilizing structures such as chutes, checkdams and drop spillways (Reference 100). A recent development in highway cut sections is the serrated side slope.

5. EFFECTIVENESS OF CONTROL

Wischmeier and Smith (Reference 136) included two factors in the universal soil loss equation which indirectly take into consideration the effectiveness of various vegetative and conservation practices in reducing or controlling erosion. These two factors are the cropping-management factor (C) and the erosion control practice factor (P). No set procedure or method to calculate percent effectiveness of a given set of erosion control methods has been prescribed, as yet. Many attempts at quantifying the percent effectiveness have been attempted (Reference 26, 36, 60, 62, 107). However, the results are sparse and non-conclusive at this point in time. One method which has much merit and which is presently in general use is that described in Reference 26, where the percent effectiveness is derived by subtracting the product of C and P factors from unity and multiplying the result by 100. More detailed information on the procedure is presented in Section VIII.

6. COSTS OF EROSION CONTROL AND SEDIMENT REMOVAL

Review of published and other available literature indicates that information on the cost of erosion control is very limited (References 12, 24, 26, 54, 55, 58, 60, 70, 92). In most cases the information presented does not adequately identify the physical conditions under which the actual work is performed. Inflationary trends, both in labor and material costs, cannot be readily divorced from the cost data, nor can improvements in erosion control techniques be simply taken into account. Furthermore, in comparing one erosion project cost to another, the method of costing used by any two different contractors is not usually described in detail in the majority of cases, to enable one to arrive at valid conclusions. Available data on cost of sediment removal methods (References 52, 53, 54, 55, 58 and 70) are very limited in scope.

7. RESEARCH IN PROGRESS

Research and development work related to soil erosion and sedimentation currently is being conducted at private, state and federal levels in the United States and in foreign countries such as Germany, Japan, and the United Kingdom. Some of the major areas of emphasis can be categorized as follows:

(1) Studies of soil cementation and/or aggregation using cement, lime, aluminum and iron oxides, carbide sludge, slag from iron mills and pulverized fuel ash.
(2) Studies of soil stabilization with vegetation, chemicals and biochemical or other soil reinforcements.
(3) Further development of the principles and practices of erosion control and soil conservation.
(4) Analysis and correlation of erosion and sedimentation with topographic and hydrologic parameters, and the development of improved soil loss prediction equations.
(5) Categorization of types of pollutants resulting from soil erosion, and definition of extent and relative importance of their occurrence.

SECTION IV

COST ESTIMATING PROCEDURES

1. INTRODUCTION

A primary objective of this study is to provide reliable data on the costs of controlling erosion and retianing sediments on construction sites, and on the costs of correcting damages resulting from soil erosion and deposition on the site and in downstream areas. When these costs are converted to comparable costs per cubic yard (cy) or per ton of sediment retained, these units can be used to judge relative economic effectiveness of various measures. Similar unit costs for the removal of sediments eroded and then deposited elsewhere also can be used for comparing methods of correcting these types of damages. Costs per unit area, such as per acre (ac) or per square yard (sq. yd) are also often used as a quick basis for comparison or for estimating overall costs of erosion control.

While such unit costs are of value they should be used with caution, as much further definition of the variables involved is needed for a true comparison to be made. Unless the soils, climatic, and site conditions are similar, the identical protective measure, for example, built at the same cost, may yield a considerably different cost per ton of material retained when constructed at another site. The economic value of a ton of clay loam retained on-site is hard to compare to a ton of sandy loam at the same, or at another site. A rigorous economic analysis of these variables is not within the scope of this study. For the purposes of this report, it is assumed that the important parameters to consider are: (1) the costs of preventing soil from eroding, or leaving a construction site and entering a stream or lake, and (2) the costs of removing soil once it has been eroded and deposited temporarily in another location. Emphasis is therefore placed on the costs of the practices or measures used. These values can be of considerable help to those involved in planning or budgeting for erosion control or sediment removal related to construction activities.

2. BASIC ELEMENTS OF CONSTRUCTION COSTS

For maximum usefulness the cost of any specific structure or measure should be defined in terms of:

(1) Makeup of Cost Figure

  (a) Equipment Costs (depreciation, interest, taxes, insurance, fuel, maintenance, and repairs)
  (b) Labor (operators, others)
  (c) Materials
  (d) Supervision
  (e) Design (if required)

(2) The procedure, measure, operations, or practice, to which it applies

(3) The time period for performing the work

(4) The physical and climatic conditions under which the work is performed

Added to the preceding may be other allowances as appropriate, such as:

Private Contractor - Overhead and Profit
Force Account - Overhead
Contingencies

The foregoing items normally are considered by an organization actually performing the work and can be termed a fundamental, or contractor, approach to cost estimating, as contrasted to the often more familiar unit price approach used by most non-contractors. A unit price, say per lineal foot (lineal ft) of diversion berm, is convenient and easy to apply, but it is difficult and possibly misleading to transfer such a unit cost derived from one particular job to another job without modification. On the other hand, if the principal elements are known, a more meaningful transfer, with proper adjustments for differences in materials, labor, and equipment costs, and site and climatic conditions, can be accomplished. While a statistical average of unit costs from many jobs has more validity, especially if derived from similar operations in a limited geographical area, this approach unfortunately is difficult to use in the cases under study in this report, because of the scarcity of available data. Even in the case of the Occoquan River Basin in an area where a considerable amount of work of this type has been performed, cost figures for separate structures or facilities were rarely found. The reason for this data scarcity is that it is normal for the contractor to have his men and equipment working on several such features during the same week, or even day, and the job accounting records do not pinpoint the manhours (m-hr) or machine-hours by each structure or practice. Indeed, in many instances the records may not even identify erosion control practices as separate work items, but may include them as part of Site Grading and Preparation. However, during interviews with contractors they were able to outline the procedures used and many important cost items.

The Contractor cost-estimating approach has been used, therefore, as the principal basis for the costs presented in this report. This procedure has not been followed in all cases, particularly for items such as dredging, where the site and performance conditions yield an almost limitless range of possible costs and are of a very specialized nature. It should be mentioned also that while the estimates presented in this report follow a contractor-approach format, every contractor has a particular format which he uses, and even more details and cost breakdowns can be used in estimating a job than are given in the examples herein presented.

Even though this fundamental approach has been used, there are still many local site conditions which can change costs from those presented herein. The more important of these influences will be discussed subsequently.

3. ASSUMPTIONS AND CONDITIONS GOVERNING COST ESTIMATES

Wherever possible, uniform application procedures were used for the several elements of the cost estimates. Unless an exception is noted thereto in the detailed estimate in Appendix A, the following conditions apply to all estimates.

(1) Climatic conditions are considered to be average.

(2) Access conditions are considered to be average.

(3) Materials, Labor and Equipment Costs are as of the end of the calendar year 1972.

(4) Labor rates include fringe benefits such as vacations, medical and pension plans, training, welfare, and promotion funds. They are intended to approximate union scale wages in the San Francisco Bay Area of California and the Washington, D. C. - nearby Virginia Area.

(5) To all labor costs, 18 percent was added to account for employer payments toward Social Security (6%) Workmen's Compensation Insurance (10%) and Unemployment Insurance (2%).

(6) 25 percent was added to the total of basic materials, labor and equipment costs to cover contractor overhead and profit.

(7) Exceptions were made to the overhead procedures set forth in Items 5 and 6 immediately preceding. For very small jobs a total overhead 45 percent was added to basic costs, rather than treating labor and general overhead charges separately.

(8) Equipment costs are based on hourly equivalent rental rates, generally assuming that the equipment can be rented at the equivalent of hourly rates based on a 40-hour per week weekly rental rate. (Monthly rental rates are usually lower, and daily rates higher than weekly rates). These costs exclude the operator, but include fuel, maintenance, repairs, interest, insurance, taxes, and depreciation.

(9) Labor and equipment charges during "move-in and move-out" are included for most non-structural practices. For structural measures it has been assumed that the erosion control work is part of an on-going construction project, and that men and equipment may be delivered from other parts of the work.

(10) Most jobs are considered to be performed on a relatively small scale. Where the work can be performed by contractor forces on a larger scale, unit costs can be reduced.

(11) Non-emergency conditions are assumed. Hence labor at overtime rates is minimal, being applicable only in a few instances.

(12) No contingency allowances are provided.

(13) Maintenance costs are not included.

4. COST ESTIMATES FOR WOOD FIBER MULCH EROSION PROTECTION PRACTICES

As an example of basic cost estimating, a breakdown of the cost of Wood Fiber Mulch erosion protection is summarized in Table 1.

The following specifications apply:

(1) Fumigate with Methyl Bromide - 24 hours prior to operation, if specified. Cost with, and without, shown.

(2) Application rates:

(a) 1500 lbs per ac - Wood Fiber Mulch @ $150 per ton
(b) 15 lbs per 1000 sq. ft - Fertilizer 11:8:4 @ $72 per ton
(c) 200 lbs per ac - Seed 75% Rye & 25% Barley @ $26 per cwt
(d) 1 lb per 100 sq. ft - Methyl Bromide (if required @ 4¢/sq. ft

Virginia Rates:

(a) Same
(b) 15 lbs per 1000 sq. ft fertilizer - 5:10:10 @ $49.45 per ton (plus limestone @ $20 per ton as and where recommended by soil scientist or agronomist)
(c) 60 lbs per ac Kentucky 31 Fescue @ $33 per cwt
40 lbs per ac Cereal rye @ $25 per cwt
(d) Same

(3) Conditions of job:

Given: Plot of land with 10-ac area, 2-hr travel time round trip to and from job, no difficulties with site access.

(4) Machine requirements

(a) Hydroseeder unit: 1 ac per hr application capacity
: 2 operators per unit @ $10/hr/man (CA)
@ 8/hr/man (VA)
: Rental rate: $30 per hr (unit alone)
: Transport cost: $25 per hr

(b) Fumigator unit : 1 ac per hr application capacity
: 2 operators per unit @ $10/hr/man (CA)
@ 8/hr/man (VA)

: Rental rate: $20 per hr
: Transport cost: $100 per job

(5) Labor conditions:

(a) Employment on one day minimum basis
(b) Overtime @ 150% of dayshift hourly rate
(c) Above operator wages include fringe benefits

(6) Move-in and move-out allowances

Above 5 ac - 2 days of Equipment and Labor

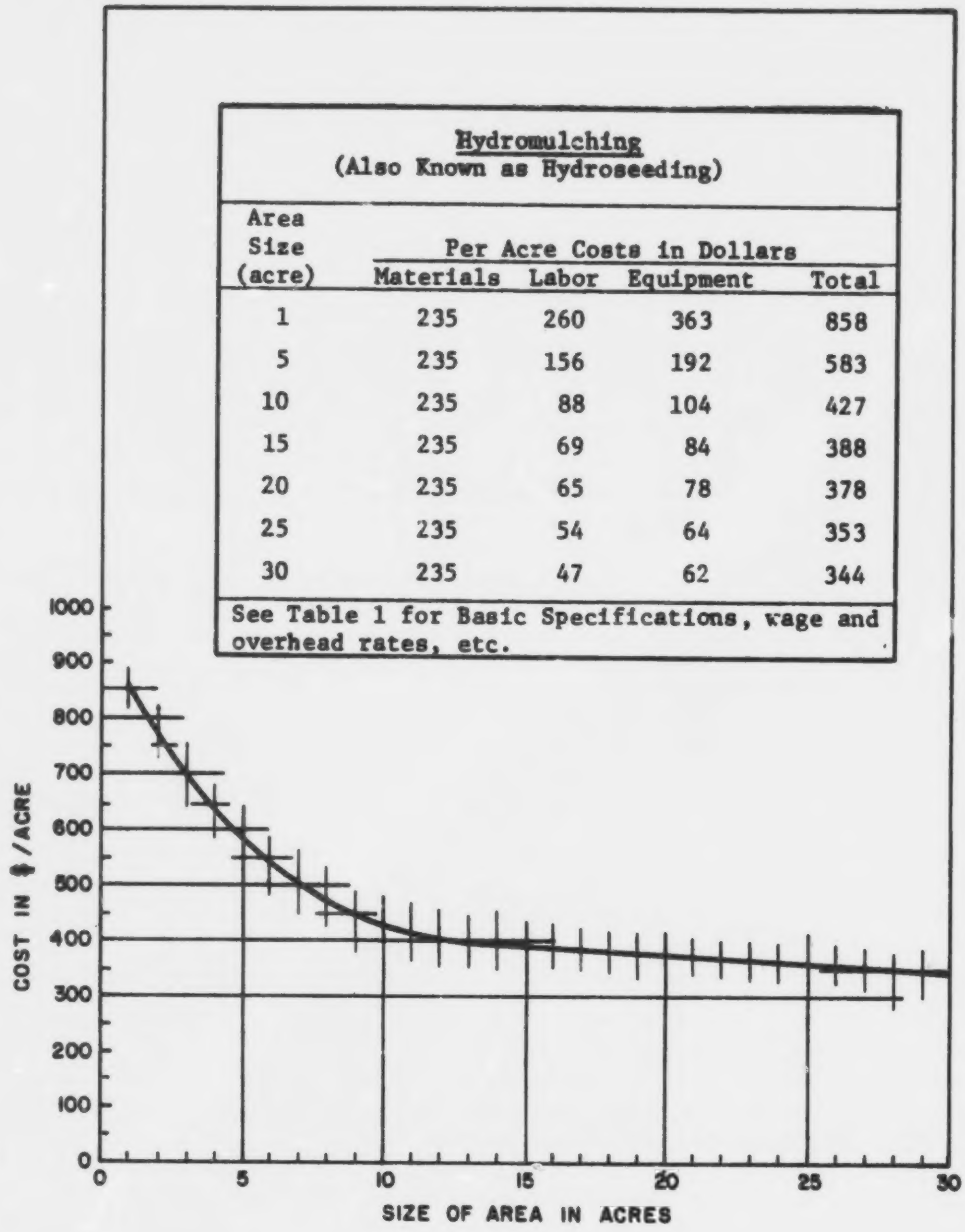
A brief study of several items of the estimate will aid in understanding its applications. These will be numbered consecutively for ease of reference, but the order of listing does not indicate relative degree of importance.

(A) Fumigation to kill noxious weeds is not usually required, but when it is, costs can increase six-fold.

(B) Costs per ac for a small plot, i.e. one ac, would be considerably more because of the resulting relative importance of move-in and move-out. Assuming that one day of time would still be required for moving in and out and performing the work, the cost per ac for a one-acre plot would increase to about $858 for California from $427 per ac, without fumigation. For jobs larger than 10 ac in size the cost per ac would decrease, but not in the same proportion. Figure 1 is a graph showing approximate variation in the per ac cost with increasing total area per job.

(C) Material costs will vary primarily with seed and fertilizer requirements, which depend greatly upon the site location and client specifications as to the grass, or grass-flower, seed mixtures desired. Seed costs can increase substantially if exotic seeds, or seeds in short supply are specified. Fertilizer requirements should not be arbitrarily specified, but should be specified by a competent technician, taking into account the vegetation to be grown and the available plant nutrients in the soil. In many instances in Virginia, and in other places in the United States where acid soils exist, lime must be added prior to the fertilizing and seeding, or nutrients, especially nitrogen, do not become readily available for plant growth. The lime requirement should be specified by a technician. When required, additional costs of from $50 to $140 per ac can be expected, depending upon the amount of lime required and the manner of application.

(D) Wage rates used are typical for prevailing union wages in the two areas in late 1972. They include fringe benefits. Lower labor rates are not uncommon.



Hydromulching
(Also Known as Hydroseeding)

Area Size (acre)	Per Acre Costs in Dollars			
	Materials	Labor	Equipment	Total
1	235	260	363	858
5	235	156	192	583
10	235	88	104	427
15	235	69	84	388
20	235	65	78	378
25	235	54	64	353
30	235	47	62	344

See Table 1 for Basic Specifications, wage and overhead rates, etc.

Figure 1. Approximate Relationship Between Cost Per Acre, and Size of Area for Wood Fiber Mulch, Fertilizer, and Seeding, Typical for San Francisco Bay Area, California 1973

(E) Employer extra labor payroll costs of 18 percent have been added to all labor costs. (10% Workmen's Compensation, 6% Social Security and 2% Unemployment Insurance.)

(F) An additional amount of approximately 11 percent of the labor charges was added to total labor charges to cover general supervision by the contractors' superintendent or foreman.

(G) Contractor Overhead and Profit is a variable with every contractor. The 25 percent figure used in these estimates represent what is considered to be a generally reasonable value for the total of both items. 15 percent could represent general overhead, and 10 percent could be considered profit but both items depend upon the skill and experience of the contractor, and the profit margin allowed in a contractor's estimate depends also upon the amount and degree of competition, and his anticipated work load.

(H) Per-acre costs as low as $200 for this practice may be mentioned occasionally. Inspection of the cost elements in Table 1 leads to the conclusion that such a unit cost would require an unusual combination of factors, such as large job, short travel time, low seeding and fertilizer requirements or costs, low wages, and tough competition. Lower costs are desirable, but when they are unusually low it is prudent to review specifications and procedures to be certain that important data has not been omitted or changed.

(I) For quick approximate estimates, the total per-acre costs for each major category, material, labor, and equipment, can be increased or decreased by proportion as appropriate to the location, specifications, and organization performing the work. More accurate estimates may be prepared by reconstructing each element of cost in the table.

5. RELATING CALIFORNIA COSTS TO COSTS IN OTHER AREAS

Prime reasons for summarizing costs in the three categories of labor, materials and equipment are to facilitate updating of costs with time, and to enable comparable costs for the same work in another geographic area to be made more easily and more accurately.

Prevailing wage rates in almost any area of the nation can be obtained from local contractor and labor organizations, the United States Department of Labor (USDL), and state and local government public works agencies. Equipment rental rates can be obtained from local rental agencies, from the Annual Rental Compilation published by the Associated Equipment Distributors (Reference 4), or the Rental Rate Blue Book (Reference 77). Agencies contemplating erosion control and correction work with their own labor forces and equipment will have knowledge of most of the costs of labor and equipment required. Materials prices for widely used construction

TABLE 1

WOOD FIBER MULCH APPLICATION BY HYDROSEEDER COST BREAKDOWN WITHOUT FUMIGATION

California Data - See Specifications for Virginia Modifications	10 ac in California Material $	Labor $	Equip $	10 ac in Virginia Material $	Labor $	Equip $
Fiber Mulch $\frac{1500 \text{ lbs}}{2000 \text{ lbs}} \times \$150 \times 10$	1,125			1,125		
Fertilizer $\frac{15 \text{ lbs}}{1000 \text{ sq.ft}} \times \frac{43560}{2000 \text{ lbs}} \times \$72 \times 10$	235			162		
Seed $200 \text{ lbs/ac} \times \frac{\$26}{100 \text{ lbs}} \times 10$	520			298		
Hydroseeder 2 men x 8 hr x \$10 plus overtime: 2 men x 2 hr x \$15		220			176	
Rental during transport time: Hydroseeder 2 hr x \$25			50			50
Rentals: Hydroseeder 10 hr x \$30			300			300
Move-in and Move-out 2 days x 2 men x 8 hr x \$10/hr		320			256	
2 days x 8 hr x \$30/hr			480			480
Labor Supervision: 0.11 (220 + 320):		60			48	
Subtotal	1,880	600	830	1,585	480	830
18% for Labor Overhead		108			86	
25% for Overhead and Profit	470	177	207	396	142	207
Grand Total	2,350	885	1,037	1,981	708	1,037
Cost per ac	235	88	104	198	71	104
Overall Cost Per Ac		427			373	

TABLE 1a

WOOD FIBER MULCH APPLICATION BY HYDROSEEDER
ADDITIONAL COST FOR FUMIGATION

California Data See Specifications for Virginia Modifications	10 ac in California			10 ac in Virginia		
	Material $	Labor $	Equip $	Material $	Labor $	Equip $
Fumigant: Methyl Bromide 4¢/sq. ft x 43560 x 10	17,424			17,424		
Labor 2 men x 8 hr x $10 plus overtime: 2 x 2 hr x $15		220			176	
Rental during transport time Lump Sum			100			100
Rentals: 10 hr x $20			200			200
Move-In & Move-out 2 days x 8 hr x $20/hr			320			320
2 days x 2 men x 8 hr x $10/hr		320			256	
Labor Supervision: 0.11 (220 + 320)		60			48	
Subtotals	17,424	600	620	17,424	480	620
18% for Labor Overhead		108			86	
25% for Overhead and Profit	4,356	177	155	4,356	142	155
Grand Total	21,780	885	775	21,780	708	775
Cost per ac	2,178	88	78	2,178	71	78
Additional Overall Cost Per Ac		2,344			2,327	

materials, such as cement, steel, lumber and ready-mixed concrete, are published frequently by local construction trade publications. However, it should be noted that prices and rates for some of the materials and equipment used in erosion control work are not published in most of the references mentioned in this section. This is because of the relatively limited amount of such work as compared to other types of construction work. Local suppliers can furnish current costs of materials but costs of special equipment, such as a Hydromulcher (Hydroseeder), must be obtained from a dealer or rental agency.

Conversion of equipment purchase costs to daily rental rates involves estimation of depreciation, interest, taxes and insurance (if any), fuel, maintenance, and repairs. This is a time consuming process, but is necessary to develop rental rates when none are available otherwise. Once obtained or developed, direct use of rental rates is much more convenient. Many contractors, and even government public works bodies, have calculated job rental rates for equipment owned by them, for ease in accounting and job estimating. In this report, equipment costs do not include operators as operators are considered under labor costs, and must be identified separately

As has been mentioned in Item I, costs for any particular area can be estimated quickly by increasing or decreasing costs shown in this report by the applicable rates for the local area and specifications. An example of how this can be done is using the Wood Fiber Mulching data from Table 1, for the Standard Practice, no fumigation.

For example, assume that the basic labor costs are \$6.50 per hr rather than the rate of \$10 per hr as shown for California. The new total cost for labor would be

$$\frac{\$6.50}{10} \times \$885 = \$575$$

instead of the \$885. The decrease in per acre cost for labor would be

$$\frac{\$10 - \$6.50}{10} \times \$88 = \$31$$

Similar proportionate calculations can be made for differences in materials and equipment costs. Assuming no changes in the latter costs, the new cost per ac would be

$$\$427 - \$31 = \$396 \text{ per ac}$$

There are several indices published periodically by private companies or governmental agencies which are used by the construction industry and others to follow construction cost trends. Engineering News-Record magazine, as an example, publishes weekly selected lists of the costs of construction materials and labor in approximately 30 major cities around the United States, and both a Construction and a Building Cost Index. The Construction Cost Index represents a fixed mix of materials and labor:

200 hr of common labor; 25 cwt structural steel shapes, millprice; 22.56 cwt (6 bbl) of Portland cement and 1,088 board-ft of 2x4 square-four-side (S4S) lumber. It does not include equipment costs. The materials-labor-equipment mixes for representative erosion control practices are summarized in the following section of this report. These mixes differ from the Construction Cost Index mix. Hence, while the ENR Construction Cost Index may give an indication of trends in the cost of erosion control work, use of local material, labor, and equipment costs to update costs given in this report will give more accurate results.

SECTION V

EROSION AND SEDIMENT CONTROL COSTS

1. INTRODUCTION

Cost estimates for a number of different types of erosion control measures have been prepared, basically using procedures and formats similar to those previously outlined in Section IV. Most of these measures are described, including numerous photographs and sketches, in the publication "Guidelines for Erosion and Sediment Control Planning and Implementation" (Reference 120).

Cost estimates are presented in this portion of the report for the California and Virginia areas, together with brief description of the control measures and their purposes. Details of each estimate, based on data from the San Francisco Bay Area of California, are presented in Appendix A, with costs divided into materials, labor, and equipment categories. Complete information on the practices is given in the previously mentioned Guidelines and the reader should refer to them for a full discussion of site evaluation, planning, and selection of effective erosion control measures, and procedures for implementation of the designs and plans.

Whereas the Guidelines present technical information on 42 sediment and erosion control products, practices, and techniques, this report presents cost estimates for 25 such items, covering a range of types and sizes. The objective herein is to provide sufficient cost data, including some variation in size of jobs, to enable reasonable cost estimates to be made of the cost of retaining sediment on construction sites. Attempts were made to limit the estimates to reasonably economic practices which could serve as a useful basis of comparison

The use of a particular brand-name or proprietary product in the cost estimate does not constitute any endorsement of the product, nor does it signify that it is the best product to use for that particular practice. In most instances, there is more than one alternative which could be substituted. The economic comparison of competitive products for a particular practice must be performed for specific installations, conditions, and requirements, and is much too detailed a process for inclusion in this report.

2. CONTROL STRUCTURES

A. Check Dams

Check dams are small structures constructed in gullies or other small watercourses. Made of concrete, masonry, rock, rock and earth, metal, wood, or other erosion-resistant materials, check dams reduce or prevent erosion by reducing velocities, promoting deposition of sediment, and stabilizing channel grades. Figures 2, 3, and 4 illustrate several types of check dams.

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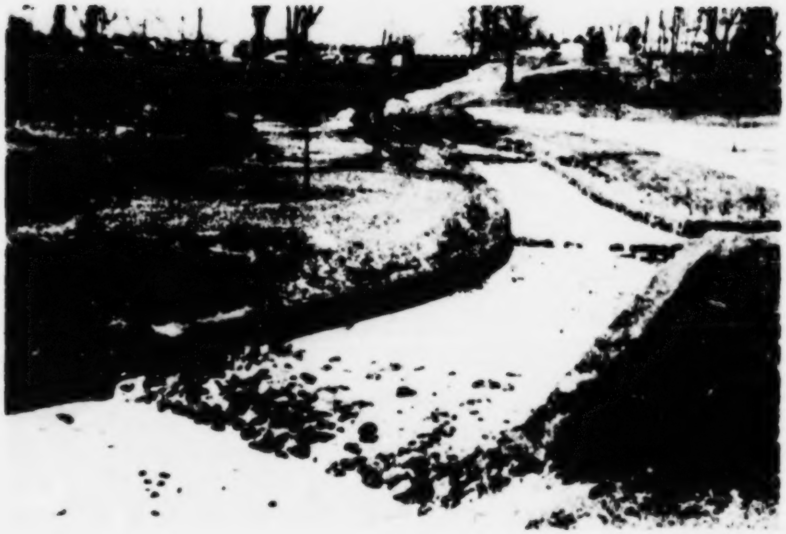
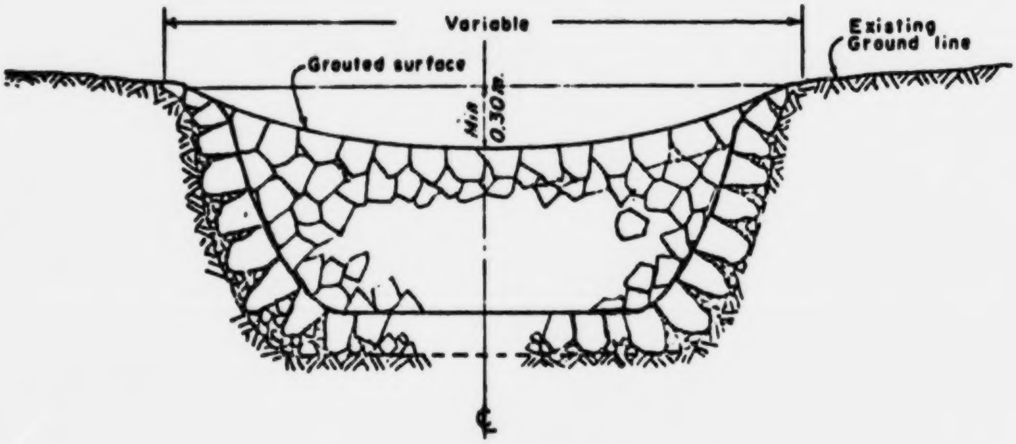
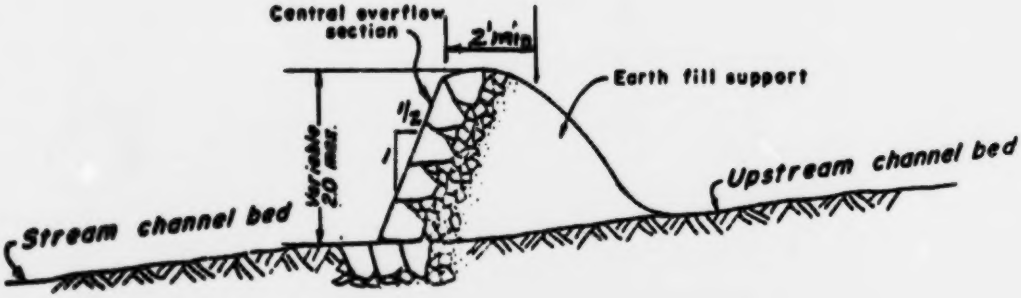


Figure 2. Small Rock Riprap Check Dams, with Gabion Sidewalls (Reference 120)


Variable
Existing Ground line
Grouted surface
Min. 0.30 m.
℄

TYPICAL SECTION CHECK DAM


Central overflow section
2' min
Earth fill support
1/2
1
Variable 2.0 max.
Stream channel bed
Upstream channel bed

VERTICAL SECTION THROUGH CENTER

Figure 3. Typical Grouted Rock Riprap Check Dam (Courtesy of Food & Agriculture Organization of the United Nations)

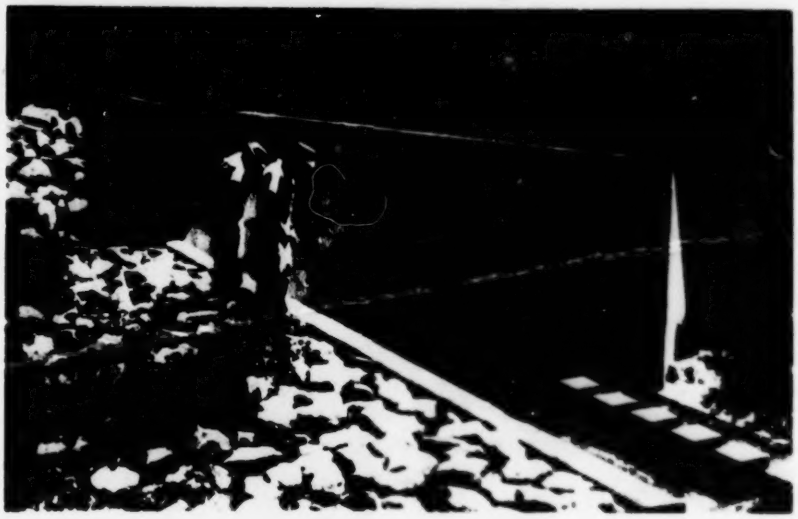


Figure 4. Concrete Check Dam with Energy Dissipator (Reference 120)

Cost Estimates- Check Dams

Cost estimates have been made for three types of check dams. The results are summarized below:

GRAVEL AND EARTH CHECK DAM

Very small, low dams, with 1 ft crest width, 2:1 downstream slope, and 4:1 upstream slope. Hand labor.

Unit costs given in $ per cubic foot (cf) of total (gravel and earth) fill.

Size		California	Virginia
1 ft high, 5 ft avg width, total volume = 19cf			
	Total cost	$ 35	
	Unit cost/cf	1.84	
1.5 ft high, 10 ft avg width, total volume = 85cf			
	Total cost	146	
	Unit cost/cf	1.72	
2 ft high, 15 ft avg width, total volume = 225cf			
	Total cost	187	
	Unit cost/cf	.83	

GROUTED ROCK RIPRAP CHECK DAM

Small low dam, with hand-placed grouted riprap masonry downstream face. See accompanying sketch (Figure 3) for typical installation.

Unit costs given per cubic foot (cf) of masonry, which is the principal cost item.

Size			
2 ft high, 5 ft avg width, cf of masonry = 56			
	Total cost	$ 392	$ 335
	Unit cost/cf	7.00	5.99
3 ft high, 10 ft avg width, cf of masonry = 131			
	Total cost	879	756
	Unit cost/cf	6.71	5.74
4 ft high, 15 ft avg width, cf masonry = 210			
	Total cost	1,428	1,237
	Unit cost/cf	6.80	5.87
5 ft high, 20 ft avg width, cf masonry = 300			
	Total cost	2,451	2,088
	Unit cost/cf	8.17	6.96

CONCRETE CHECK DAM

Small structure constructed of reinforced concrete (Figure 4).

Unit costs are per cubic yard (cy) of reinforced concrete on drawings.

Size		California	Virginia
2 ft 4 in. high x 5 ft wide x 4 ft long Volume reinforced concrete = 1.9cy			
	Total cost	$ 1,136	$ 1,027
	Unit cost/cy	598	541
5 ft 6 in. high x 9 ft 8 in. wide x 8 ft long Volume reinforced concrete = 10.8cy			
	Total cost	3,108	2,802
	Unit cost/cy	288	259
5 ft high x 17 ft 6 in. wide x 14 ft long Volume reinforced concrete = 17.8cy			
	Total cost	4,647	4,150
	Unit cost/cy	261	233
7 ft high x 20 ft wide x 20 ft long Volume reinforced concrete = 33.0cy			
	Total cost	7,154	6,430
	Unit cost/cy	217	195

B. Chutes/Flumes

Chutes and flumes are channels constructed of concrete or comparable material that are designed to conduct runoff downslope from one elevation to another without erosion of the slope. They may be installed as temporary, in interim, or permanent structures downslopes where concentrated runoff would cause slope erosion. Figure 5 illustrates a typical chute/flume.

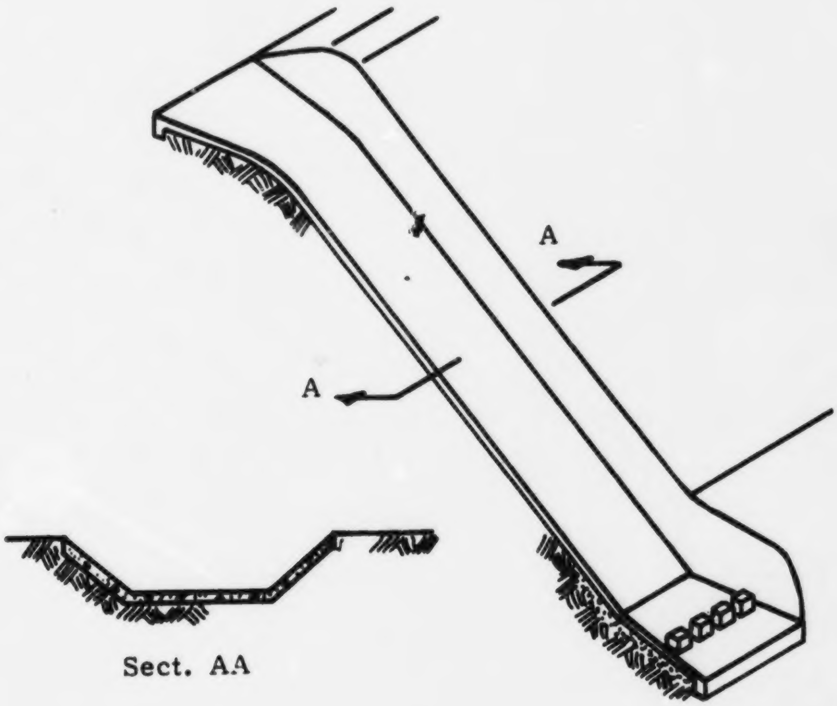


Figure 5. Chute/Flume (Reference 120)

Cost Estimate - Concrete Flume

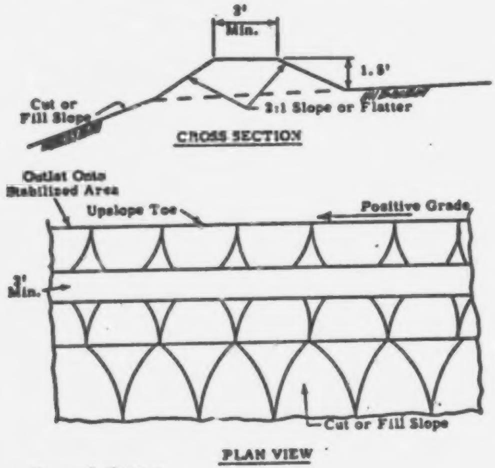
A cost estimate was made for a concrete chute constructed of pneumatic concrete reinforced with wire mesh, and without energy dissipating blocks, as follows:

Dimensions of Flume: Bottom width = 3 ft
Depth = 1 ft
Side Slopes = 1:1
Concrete thickness = 3 in.
Length = 40 ft

	California	Virginia
Total Cost:	$1,298	$ 1,134
Unit Cost:		
Per lineal ft length	$ 32.45	$ 28.35
Per sq ft of concrete	5.40	4.72

C. Diversion Dikes

Diversion dikes are small temporary ridges of soil (Figure 6) constructed at the top of cut or fill slopes to divert overland flow from small areas away from newly-constructed, unstabilized, or unprotected slopes. They normally are used as temporary or interim measures, but are sometimes appropriate as permanent installations.


3'
Min.
1.5'
Cut or
Fill Slope
2:1 Slope or Flatter
CROSS SECTION
Outlet Onto
Stabilized Area
Upslope Toe
Positive Grade
3'
Min.
Cut or Fill Slope
PLAN VIEW

General Notes:

a. Drawings not to scale.
b. Outlet to discharge into stabilized area.

Figure 6. Diversion Dike (Reference 120)

Cost Estimate - Diversion Dike

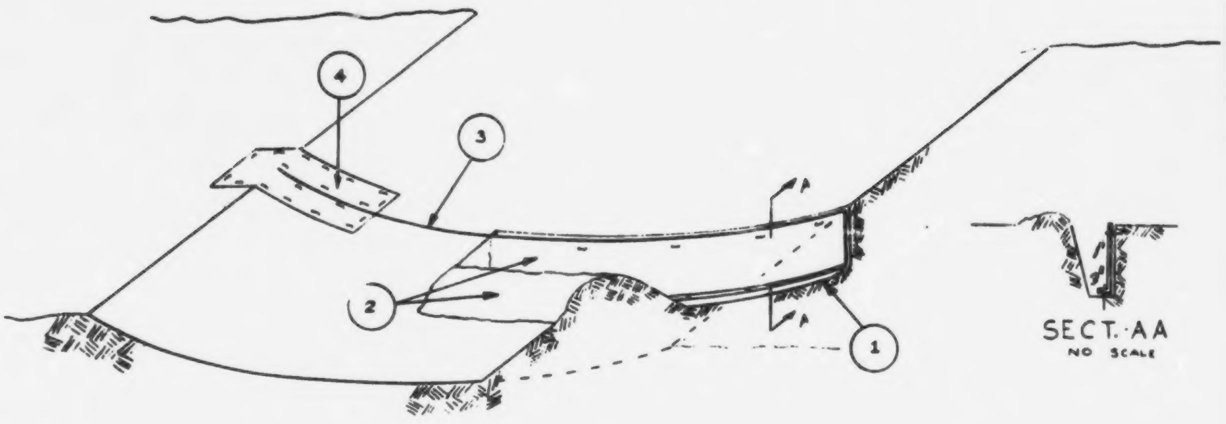
A cost estimate was prepared for a well-compacted embankment with final dimensions as shown on Figure 6. It should be noted that many diversion dikes are not compacted as much as really needed (some are constructed more like level spreaders) and costs per lineal ft are less than the estimates shown here. The following estimate was prepared for a dike 43 ft long, with 15 cy of earth as final compacted embankment:

	California	Virginia
Cost per lineal ft of dike =	$ 4.51	$ 3.70
Cost per cy of embankment =	12.93	10.65

D. Erosion Checks

Erosion checks (Figures 7 and 8) are porous, mat-like materials installed in slit trenches oriented perpendicular to the direction of flow in ditches or swales. They prevent the formation of rills and gullies by permitting subsurface water migration without the removal of soil particles.

Figure 7. Fiber Glass Erosion Check (Reference 120)



1. Cutaway of fiber glass installation in bottom of trench.
2. Cutaway of fiber glass installation in trench with spoil pile.
3. Trench with fiber glass erosion check installed.
4. Cap strip of blanketing material over completed erosion check.

Figure 8. Erosion Check (Reference 120)

Cost Estimate - Erosion Check

Cost estimates were made using jute mesh rather than fiber glass mesh. The procedure for either type of material is the same and the primary variable would be the material, which, in the case of jute mesh, is a very small part of the cost, the greater portion being the cost of labor.

The following estimate was prepared for 152 lineal ft of jute mesh, which is approximately the quantity two laborers can excavate and place in one day under average conditions, as follows:

	California	Virginia
Total Cost	$ 522	$ 403
Cost per lineal ft	3.43	2.65

E. Filter Berms

Filter berms (Figure 9 and 10) are temporary ridges of gravel or crushed rock constructed across a graded right-of-way to retain runoff while at the same time allowing construction traffic to proceed along the right-of-way. They are used primarily across graded rights-of-way that are subject to vehicular traffic, but also are applicable for use in drainage ditches prior to roadway paving and establishment of permanent ground cover.

Figure 9. Filter Berm - Installed (Reference 120)

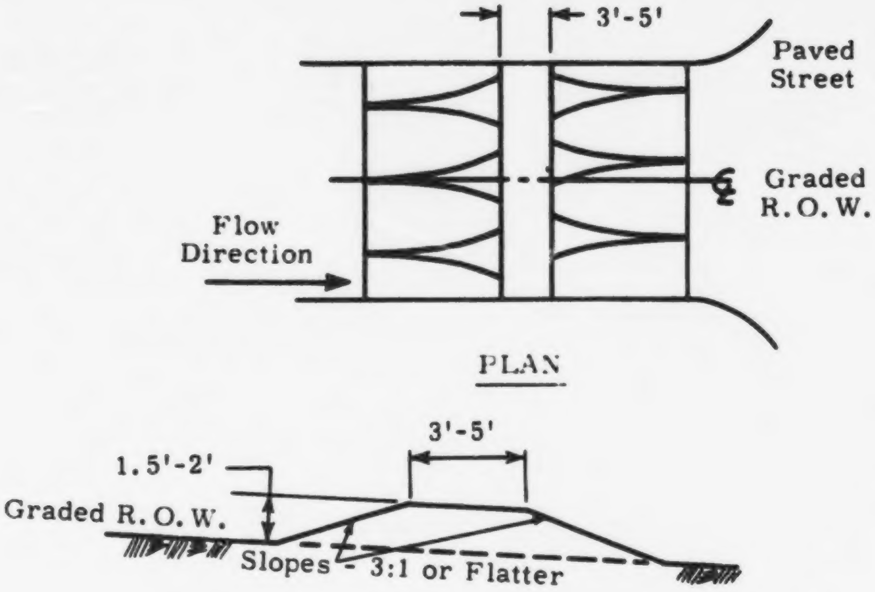

3'-5'
Paved Street
Graded R.O.W.
Flow Direction
PLAN
3'-5'
1.5'-2'
Graded R.O.W.
Slopes - 3:1 or Flatter

Figure 10. Filter Berm - Cross Section (Reference 120)

Cost Estimate - Filter Berm

An estimate for a berm having about 30 cy of gravel, and being about 58 ft long is as follows:

	California	Virginia
Total cost	$319	$296
Unit cost, per lineal ft	5.50	5.11
Unit cost, per cy	10.63	9.87

F. Filter Inlets

Filter inlets (Figures 11 and 12) are temporary filters of gravel or crushed rock constructed at storm sewer curb inlet structures. Their purpose is to retain sediment on-site by slightly retarding and filtering storm runoff before it enters the storm sewer system.

Figure 11. Filter inlet - Installed (Reference 120)

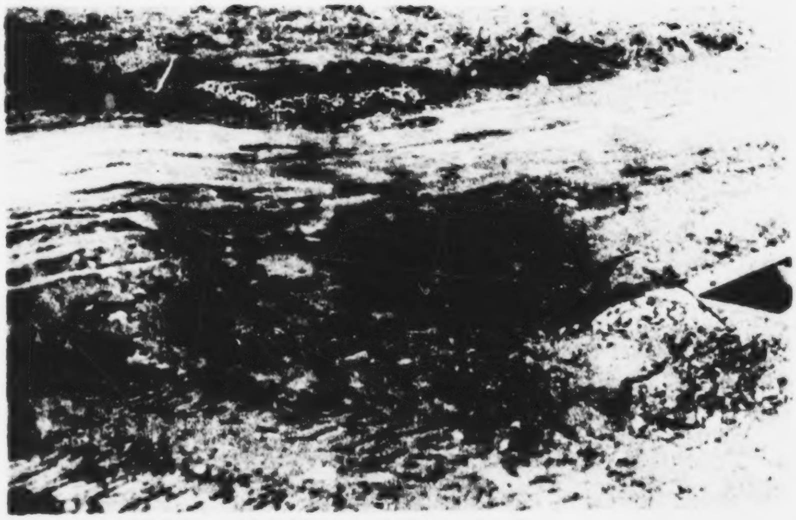


Figure 12. Filter Inlets - Installed (Reference 120)

Cost Estimate - Filter Inlet

If access by gravel trucks is possible, costs for filter inlets will be approximately the same per cubic yard as for filter berms. If material must be retransported by a front-end loader, costs will be considerably higher. The following costs include gravel, labor, and equipment:

	California	Virginia
Access by truck, unit cost per cy	$ 10.63	$ 9.87
If rehandled by front-end loader, unit cost per cy	$ 16.00	$ 15.30

G. Flexible Downdrains

Flexible downdrains are flexible conduits (Figures 13 and 14) of heavy duty fabric or other materials, to conduct storm runoff from one elevation to another without erosion of the slope. They are used as temporary or interim structures down slopes where concentrated runoff would cause excessive slope erosion.

Cost Estimate - Flexible Downdrain

Estimates were made for 300 lineal feet of flexible downdrain, with the connection assumed to be to a culvert at the upper end. Costs for riprap or other energy dissipation at outlet were not included, in the following estimates:

	California	Virginia
Total costs, 300 lineal ft of downdrain, in place	$ 2,203	$ 2,180
Unit cost per lineal ft	7.34	7.26

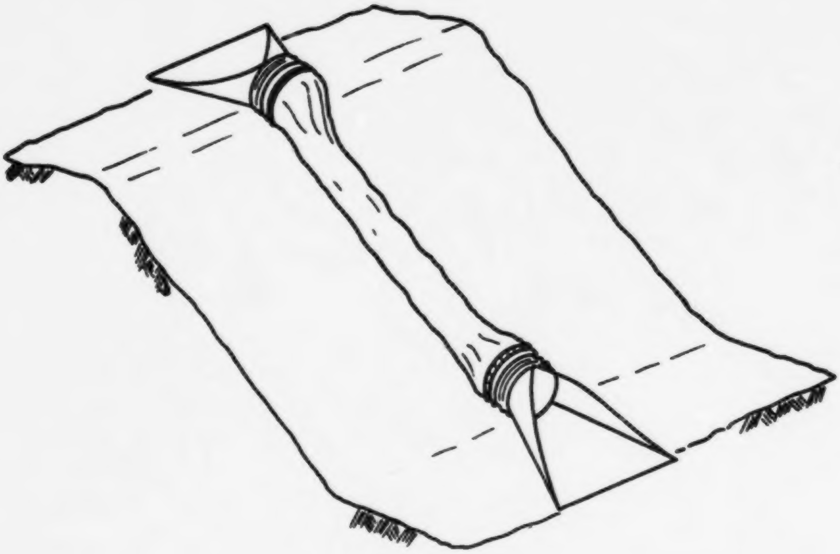


Figure 13. Flexible Downdrain - Isometric (Reference 120)

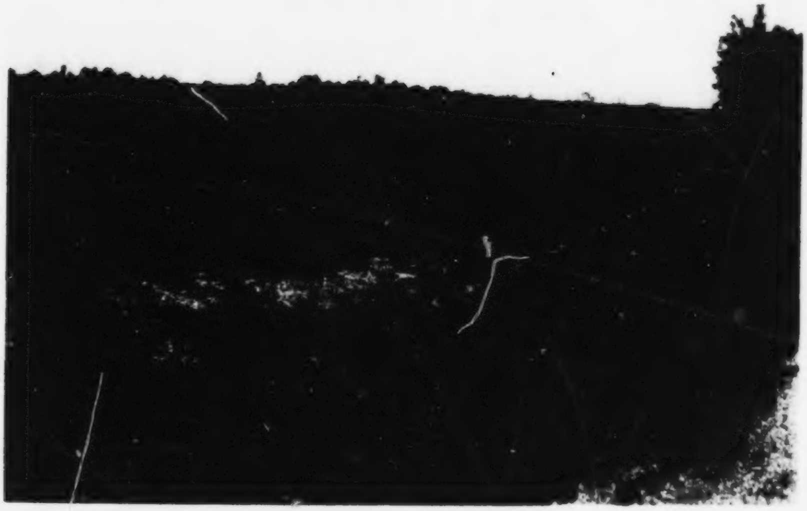


Figure 14. Flexible Downdrain - Installed (Reference 120)

H. Flexible Erosion Control Mats

Flexible erosion control mats (Figures 15, 16, and 17) are special flexible fabric forms into which fluid mortar is injected under pressure, using special techniques, after the forms are in place. In erosion control work they are used for channel lining, revetments, levee facings, shoreline stabilization, and check dams. They can be placed above or below water surfaces, and are adaptable to almost any type of soil conditions.

Cost Estimate - Flexible Erosion Control Mat

The following estimate was made for a channel 25 ft wide and 0.25 mi. long (i.e. 33,000 sq. ft of flexible mat required):

	California	Virginia
Total cost	$38,824	$36,600
Unit cost, per sq. ft	1.18	1.11

Figure 15. Schematic of Flexible Mat Subsequent to Grouting (Courtesy of VSL Corporation)

Figure 16. Installation of Flexible Erosion Control Mats in a Drainage Canal with High Ground Water Table (Courtesy of VSL Corporation)

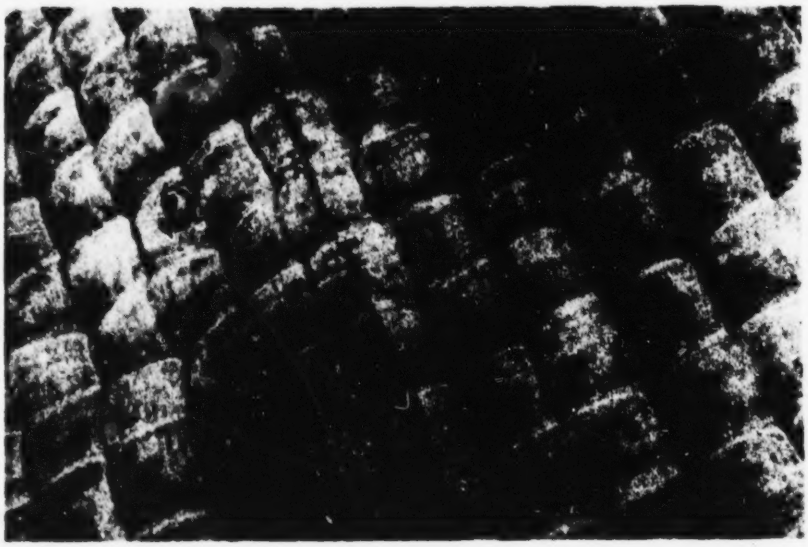


Figure 17. Detail of Installed Flexible Erosion Control Mats (Courtesy of VSL Corporation)

I. Gabions

Gabions are large, multi-celled, rectangular wire mesh boxes (Figures 18 and 19), filled with rock. Individual gabions serve as building blocks which when properly wired together, form monolithic, yet flexible, structures and mats. They are used in channels, revetments, abutments, check dams, retaining walls, levee facings, and other erosion control structures.

Cost Estimates - Gabions

Estimates were made for 3 sizes of small jobs, using gabions 1 ft deep, as follows:

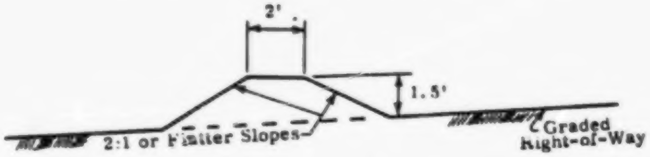
Unit costs are per sq. yd of surface area	California	Virginia
10 sq. yd	$ 30.10	$ 24.82
100 sq. yd	15.49	13.85
1000 sq. yd	12.67	11.35

Figure 18. Gabions - Channel Bank Protection (Reference 120)

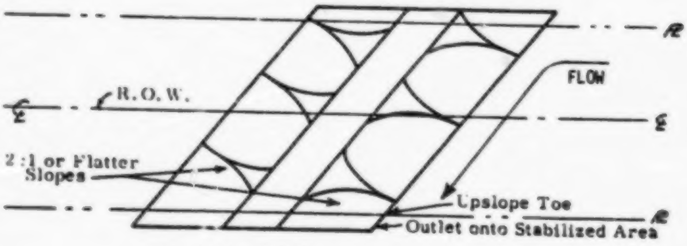
J. Interceptor Dikes

Interceptor dikes are temporary ridges of compacted soil (Figures 20 and 21), constructed across a graded right-of-way. They reduce erosion by intercepting storm runoff and diverting it to temporary outlets where it can be disposed of with minimal erosion. Interceptor dikes are normally used across graded rights-of-way that are not subject to vehicular traffic.

Figure 19. Gabions - Channel Lining, Check Dam, and Bank Protection (Reference 120)


2'
1.5'
2:1 or Flatter Slopes
Graded Right-of-Way

CROSS SECTION


℄
FLOW
R.O.W.
℄
℄
2:1 or Flatter Slopes
Upslope Toe
℄
Outlet onto Stabilized Area

PLAN VIEW

a. Drawings not to scale.
b. Top width may be widened, slopes may be flattened.
c. Outlet should function with minimal erosion.

Figure 20. Interceptor Dike (Reference 120)

Cost Estimate - Interceptor Dikes

The cost estimates for well-constructed diversion dikes, as presented on page 31 are representative of the cost for interceptor dikes. In many instances, for example along forest roads, a log with earth backfill can be placed at a much lower cost per lineal foot. Hence, diversion dike costs are probably at a higher range of values.

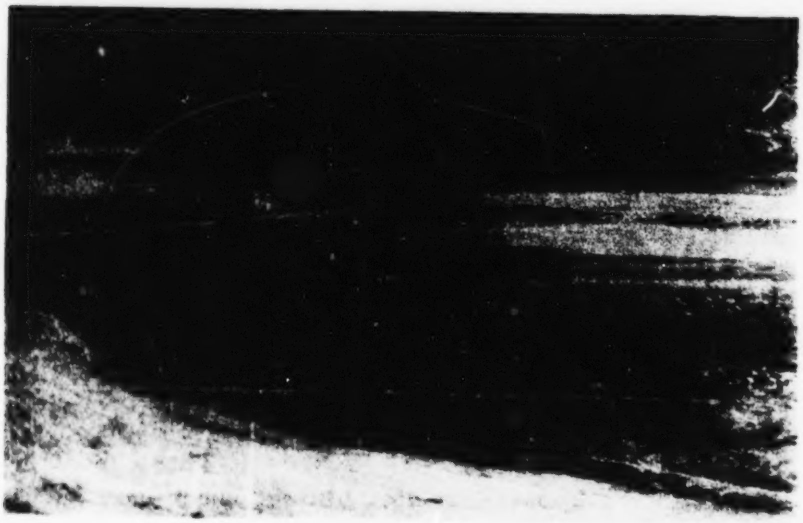


Figure 21. Interceptor Dike - Installed (Reference 120)

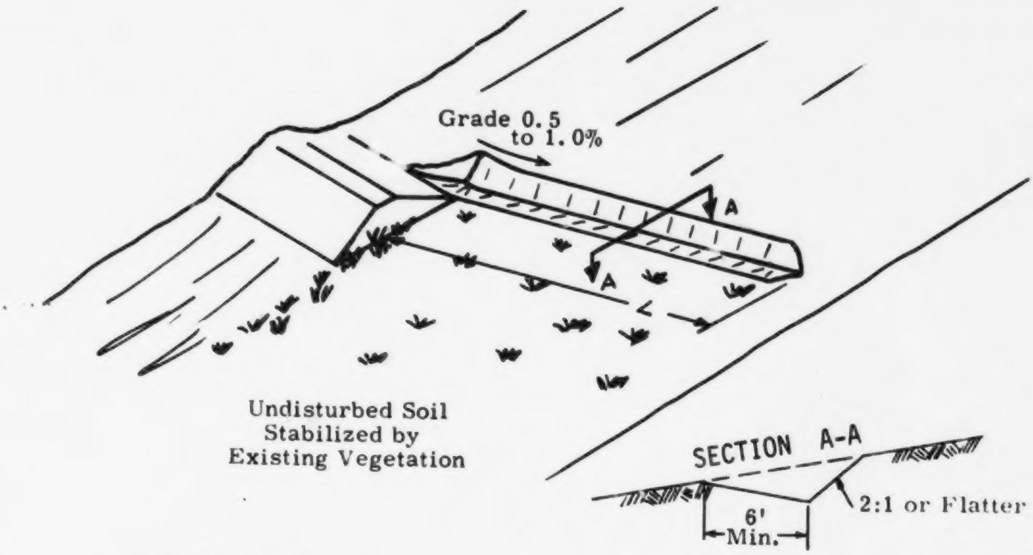
K. Level Spreaders

Level spreaders are outlets constructed at zero grade across a slope where concentrated runoff may be spread at nonerosive velocities, in the form of sheet flow, over undisturbed areas stabilized by existing vegetation. Figures 22 and 23 illustrate typical level spreaders.

Cost Estimates - Level Spreaders

The following estimates were made for small jobs for three lengths of spreaders, constructed by bulldozer.

	California	Virginia
Length of level spreader:		
15 ft Unit cost per lineal ft	$ 3.80	$ 3.16
44 ft Unit cost per lineal ft	1.91	1.57
78 ft Unit cost per lineal ft	1.63	1.36


Grade 0.5 to 1.0%
A
A
L
Undisturbed Soil Stabilized by Existing Vegetation
SECTION A-A
6' Min.
2:1 or Flatter

Drawing not to scale.

Figure 22. Level Spreader (Reference 120)

Figure 23. Small Diversions, Very Similar to Level Spreaders. If Both lip and bed are constructed at zero grade these would be level spreaders. (Reference 120)

L. Sandbag Sediment Barriers

Sandbag sediment barriers are temporary barriers or diversions constructed of sandbags. The barriers are built to retain sediment on-site by slowing storm runoff and causing the deposition of sediment at the structure, and are used at storm drain inlets, across minor swales and ditches, and for other applications where the structure is of a temporary nature.

Cost Estimate - Sandbag Sediment Barrier

The following estimate was prepared for one day of sandbagging by four laborers and a foreman, assuming that 180 bags would be filled and placed in one day.

	California	Virginia
180 bags, cost per sandbag	$ 3.10	$ 2.44

M. Sectional Downdrains

Sectional downdrains (Figure 24) are prefabricated, sectional conduits of half-round or third-round, pipe, corrugated metal, concrete, bitumized fiber, asbestos cement, or other material. They conduct storm runoff from one elevation to another without slope erosion, and are used as a temporary, interim, or premanent structure on slopes where concentrated runoff would cause excessive slope erosion.

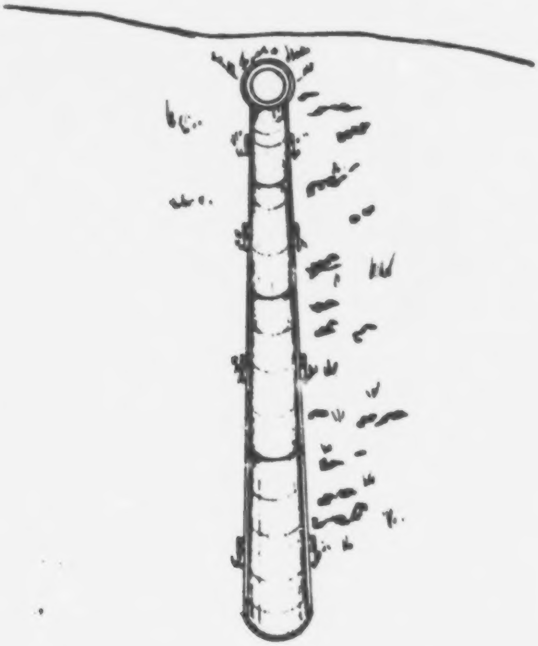


Figure 24. Sectional Downdrain

Cost Estimate - Sectional Downdrains

Two different lengths of 24 in.-diameter sectional downdrains were considered. The cost estimates are as follows:

		California	Virginia
40 ft length	Total Cost	$582	$ 474
	Unit cost per lineal ft	14.55	11.85
234 ft	Total Cost	2,555	2,136
	Unit cost per lineal ft	10.91	9.13

N. Sediment Retention Basins

Sediment retention basins are storage areas behind dams or barriers and are constructed for the primary purpose of trapping and storing sediment and debris produced by storm runoff from tributary watersheds. They sometimes are referred to as Debris Basins, especially in the southwestern United States. While in a strict technical sense the term "basin" applies only to the storage area, in common usage the term is understood to include also the dam or barrier. As temporary measures they are used across channels and drainageways that are on, or adjacent to, construction sites, to trap and retain sediment generated during on-site construction activities. In many instances they are also used on a longer-term basis to protect downstream channels and properties from annual threats of unwanted sediment and debris carried by storm runoff. Illustrative examples of sediment retention basins are shown on Figures 25, 26, and 27.

Cost Estimates - Sediment Retention Basins

Three cases of sediment retention basins were estimated. Well-designed and engineered structures 6 ft to 8 ft in height were assumed. Land costs are not included in the following tabulation of Unit costs.

		California	Virginia
6 ft high, 30 ft avg length To			
	Total Cost	$ 1,833	$ 1,516
	Unit cost per cy	13.78	11.40
7 ft high, 30 ft avg length			
	Total cost	2,189	1,850
	Unit cost per cy	12.88	10.90
8 ft high, 40 ft avg length			
	Total cost	2,996	2,560
	Unit cost per cy	10.51	8.99

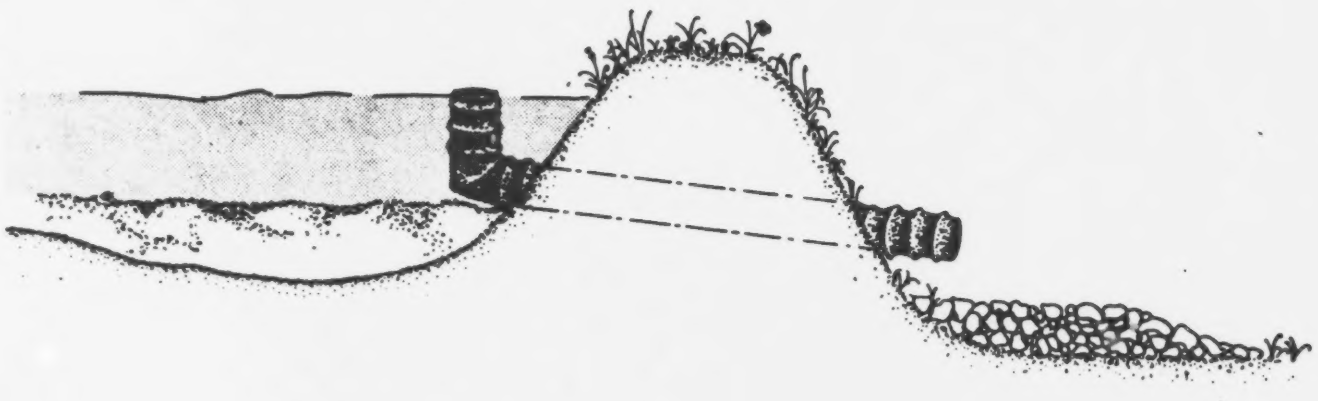


Figure 25. Small Sediment Basin with Outlet Pipe Discharging on Energy Dissipator to Prevent Erosion at Discharge End. (Revised from California Division of Soil Conservation, Reference 92.)

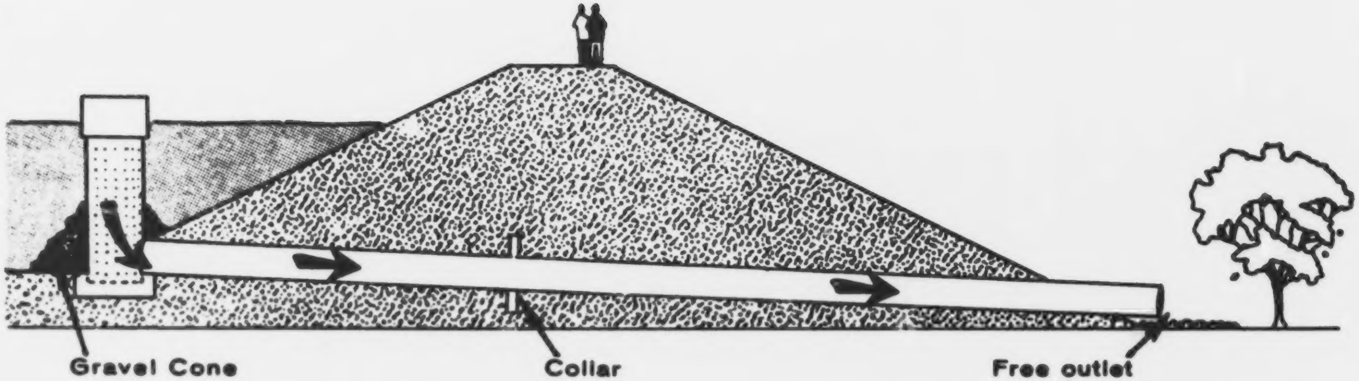

Gravel Cone
Collar
Free outlet

Figure 26. Large, Well-Engineered Sediment Basin Dam. Note Outlet Pipe with Riser, Gravel Core Filter, and Seepage-path Cut-off Collars on Outlet. (Revised from Fairfax County, Reference 92, Figure No. 35.)

Figure 27. Sediment Retention Basin - Small, Less Than 1/4-Acre in Size (Reference 120)

O. Straw Bale Sediment Barriers

Straw bale sediment barriers are temporary berms, diversions, or other barriers that are constructed of baled straw, to retain sediment on-site by retarding and filtering storm runoff. They are used at storm drain inlets, across minor swales and ditches, as training dikes and berms, along property lines, and for other applications where the structure is of a temporary nature and structural strength is not required. Illustrations of straw bale sediment barriers are presented on Figures 28, 29, 30, and 31.

Cost Estimates - Straw Bale Sediment Barriers

Estimates were made for straw bales laid in place and staked. The cost per bale is approximately the same whether bales are used for storm sewer inlet protection or as barrier. Barriers also may include gravel weir outlets. The estimates are as follows:

		California	Virginia
Storm sewer inlet,	7 bales/inlet, 3 inlets/day		
	Total cost/inlet	$ 55.00	$ 46.34
	Cost/bale	7.86	6.62
Straw Bale Barrier		7.86/bale	6.62/bale
	plus	10.44/weir	8.99/weir

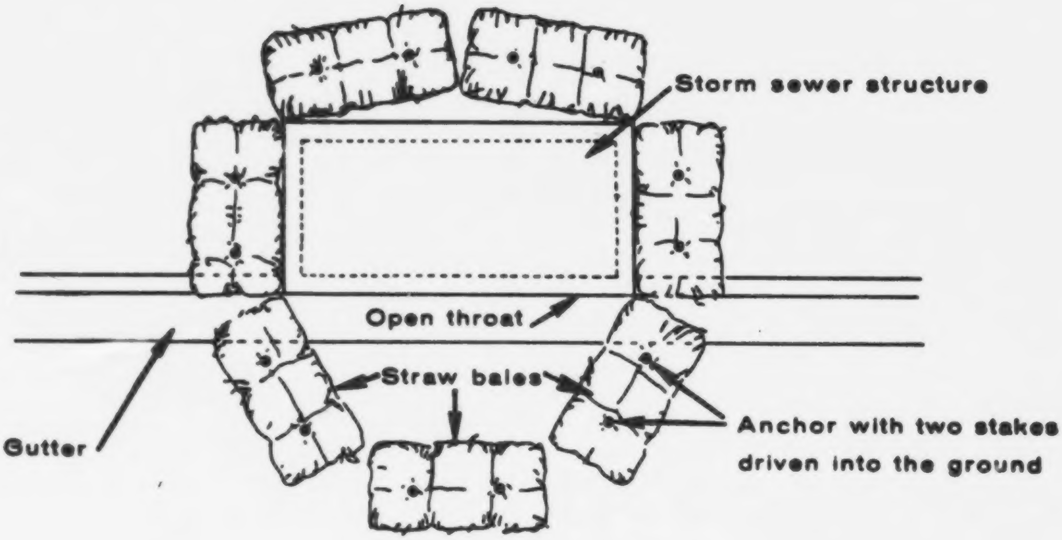

Storm sewer structure
Open throat
Gutter
Straw bales
Anchor with two stakes driven into the ground

Figure 28. Temporary Barrier of Hay Bales to Prevent Sediment-laden Water from Entering Incomplete Storm Sewer System. (Revised from Fairfax County, Reference 92, Figure 17.)

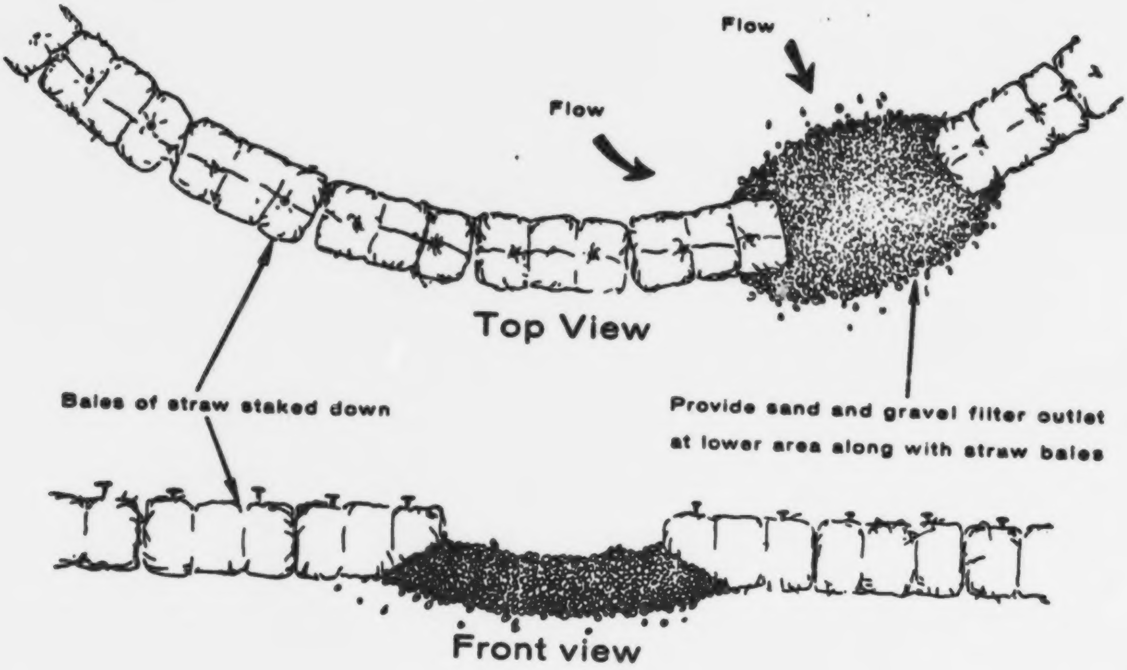

Flow
Flow
Top View
Bales of straw staked down
Provide sand and gravel filter outlet at lower area along with straw bales
Front view

Figure 29. Semi-pervious Barrier of Hay Bales with More Pervious Embankment of Sand and Gravel for Spillway. (Revised from Fairfax County, Reference 92, Figure 31.)

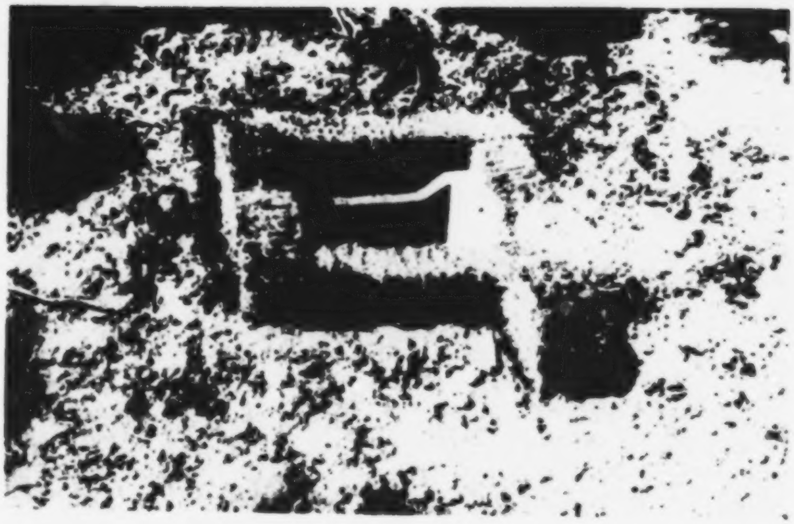


Figure 30. Straw Bales at Storm Drain Inlet (Reference 120)

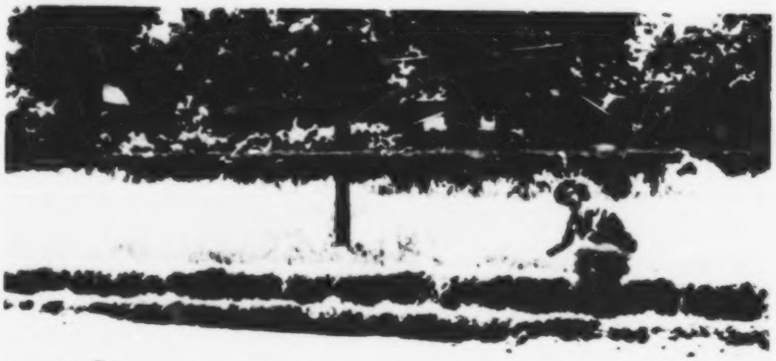


Figure 31. Straw Bale Structure on Property Line (Reference 120)

3. FIBER MULCHES, MULCH BLANKETS, NETTINGS, AND SODDING

A detailed cost estimate for seeding, fertilizing, and providing a wood fiber mulch by a hydroseeder has been presented previously (Section IV, Table 1). Estimates for several other representative similar practices were prepared and are summarized in Table 2. Explanations of all but two methods are given on the following pages. These explanations were taken from Reference 120. Technical instructions for the sodding practices are not included, although the detailed cost sheets in Appendix A provide information on the requirements.

Although costs are given on a per ac basis for all practices in this protion of the report, they are not always directly comparable. For example, on very steep slopes wood fiber mulch would not provide good protection, while excelsior would do so, even though it is more expensive. Generally, more expensive practices are required on the steeper slopes. In making a selection for a particular site and situation, the economic life of the practice and its maintenance costs must be considered, as well as the initial installation costs, the application requirements for a particular soil, slope, or climate, and the desired end result. There are so many variables to be considered that only broad general conclusions should be drawn from the unit costs presented herein.

Detailed cost estimates showing costs of material, labor, and equipment are provided in Tables A-1 through A-27, Appendix A.

TABLE 2

SUMMARY OF REPRESENTATIVE COSTS FOR FIBER MULCHES, BLANKETS, ETC.

Practice or Method	Cost per Ac of Area California	Virginia
Excelsior Mats	$12,200	$10,200
Jute Netting	7,700	6,700
Straw or Hay applied by blower	1,200	1,100
Woodchips, 3 in. cover unseeded	8,000	7,200
Woodchips, 3/4 in. cover	3,100	2,800
Wood Fiber Mulch by Hydroseeder	430	370
Sod, 4 in. sq plugs	11,300	10,300
Sod Blankets	14,800	14,300
Chemical Soil Stabilizer	1,300	1,250

Notes: (1) All of the above estimates include fertilizer and seed necessary to provide a vegetative cover, except the 3 in. deep woodchip cover estimate. Seed, of course, is not required for sodding. See detailed estimates in Appendix A for application rates.

(2) Costs are not directly comparable. See text. Terrain, use of land, climate, time of year, degree of protection desired, and other factors must be considered to make an economic comparative evaluation for each specific situation

A. Excelsior Blankets

Excelsior blankets (Figure 32) consist of machine-produced mats of curled wood excelsior of 80 percent eight-inch or longer fiber length. The top side of each blanket is covered with a 3 in. x 1 in. weave of twisted Kraft paper, biodegradable plastic mesh, or similar material, that has a high wet strength. These blankets protect the soil from the energy of falling raindrops and overland flow, conserve soil moisture, and serve as insulators against intense solar radiation. In general, the blankets are rolled out on the seeded area to be protected and are stapled into place. Suggested staple application rate, under normal conditions, is five staples per six linear feet of blanket. The fact that the blankets are secured to the soil by metal staples make this product resistant to erosion by concentrated storm runoff. The blankets can, therefore, be used in critical areas such as swales, ditches, steep slopes, highly erodible soil, etc.

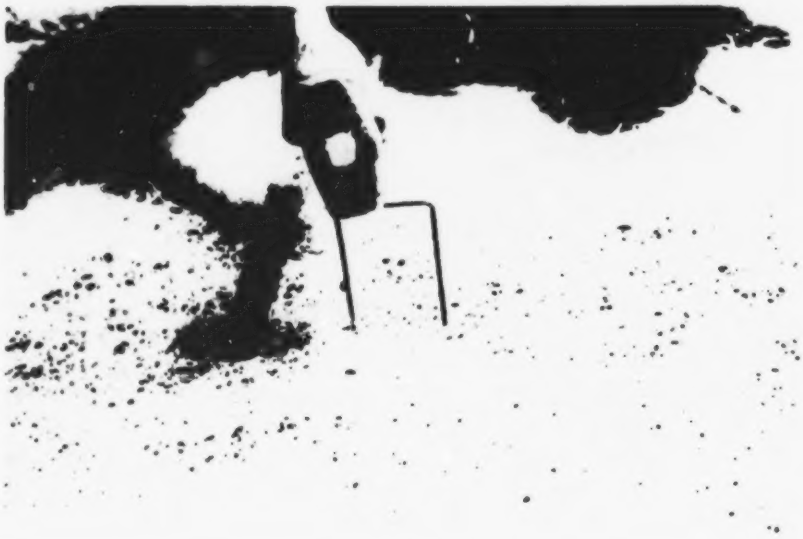


Figure 32. Excelsior Blanket and Staple (Reference 120)

B. Jute Netting

Jute netting (Figure 33) consists of a heavy woven mesh, of undyed and unbleached twisted jute fibers of rugged construction. The netting can be treated to be smolder resistant. It is commonly available in individual rolls, about 4 ft wide and is used in the establishment of vegetation in critical areas. As a mulching product, it dissipates the energy of falling rain drops, and overland flow, conserves soil moisture, and serves as an insulator against intense solar radiation. The thick strands and heavy weave enable this product to withstand the higher flow velocities associated with critical swales, ditches, median strips, etc. Seeding may be done before and after installation. The netting is unrolled over the soils to be protected with the edges overlapped, and stapled to the soil beneath. The upstream end of each strip is buried at least four inches deep and reinforced by a row of staples about four inches downhill from the trench.

Figure 33. Jute Netting Being Installed (Reference 120)

C. Straw or Hay

Straw or hay often are used as a mulch product (Figure 34). In this capacity they dissipate the energy of falling raindrops and overland flow, conserve soil moisture, and serve as an insulator against intense solar radiation. They are used on newly-seeded areas, and can be used also as a temporary mulching measure to protect bare soil areas that have not been seeded. The latter practice is applicable only for relatively short periods of time or until the next seeding season has been reached.

Straw or hay mulch can be applied by hand spreading (shaking) on small plots and by mulch blowing equipment on larger areas. It is applied at rates of from one to two tons per acre. (In California four tons total in two applications is a common procedure for highway erosion protection). Straw and hay mulch should be tacked to insure against excessive losses by wind and water. Liquid and emulsified asphalt are the most commonly used mulch tacks. However, other chemicals and netting products are available for use as mulch tacks. Mulch anchoring tools can also be utilized to anchor straw and hay. This equipment consists of a series of notched discs which punch and anchor the mulch material into the soil. Soil must be moist, free of stones, and loose enough to permit disc penetration to a depth of two to three inches if this mulch anchoring technique is to perform in a satisfactory manner.

One advantage of this type of mulch is that it is well-adapted to later overseeding, even up to six months later. Thus mulching can be done immediately after fine grading is completed, with seeding delayed until the most appropriate time. Important present disadvantages are the high cost for labor and/or equipment and the greater length of time required for placement, as compared to hydromulching.

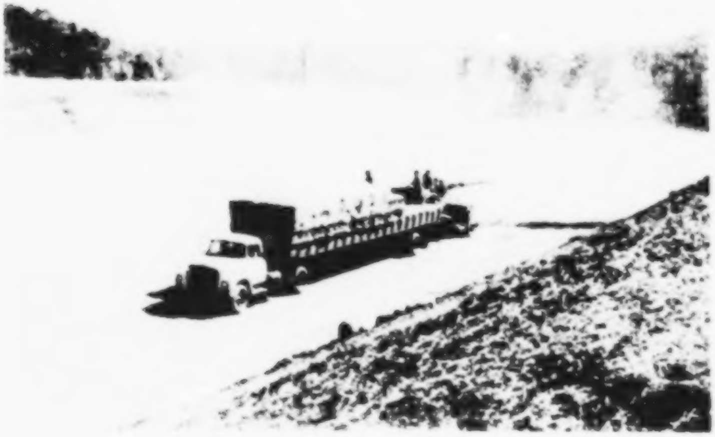


Figure 34. Large Straw Mulching Operation (Reference 120)

D. Woodchips

Chips of wood are produced by processing tree trunks, limbs, branches, etc., in woodchipping machines. The chips are placed back on the site from which they originate, or are placed in trucks for transport to other sites where they are spread for use. Chips are used as a temporary or interim erosion control technique to protect bare soil areas that have not been seeded. They are also used as a mulch product on newly-seeded areas. In this capacity, they conserve soil moisture during dry periods, dissipate energy from falling raindrops, serve as insulators against intense solar insolation, and reduce erosion caused by overland sheet flow. Woodchips may also be used on pathways and to reinforce leaf mold, duff, etc., in wooded areas that are to be preserved.

As a temporary technique on unseeded areas, the chips are placed by machine or spread by hand tools. Application rates range from 4 to 6 cf of woodchips per 100 sq. ft of area. This application rate is ample to protect bare soil under normal conditions. If intensive foot or vehicle traffic is anticipated, this rate may be increased to the point where woodchip depths of several inches are attained. This very heavy application rate is particularly applicable to yard areas adjacent to homes under construction if autos and light trucks drive and park in the yard area.

As a mulching product on newly-seeded areas, woodchips may be placed by machine blower or by hand from stockpiles (Figure 35). Application rates of 60 to 100 cy per ac are commonly recommended. Mulching with woodchips has proven successful when used with late fall seeding operations that require protection over winter. Experimental work is needed to perfect seed mixtures for this type of operation. However, the wood chip mulch has proven to be satisfactory under these conditions.

Figure 35. Spreading Wood Chips on Homesites (Reference 120)

E. Wood Fiber Mulch

Wood fiber mulch is a natural, short fiber product, produced from clean, whole wood chips. A nontoxic dye is used to color the mulch green in order to aid visual metering in its application. It is evenly dispersed and suspended when agitated in water, and when applied uniformly on the surface of the soil, the fibers form an absorbent cover, allowing percolation of water to the underlying soil.

Wood fiber mulch contains no growth or germination-inhibiting factors. In hydroseeder slurries, it is compatible with seed, lime, fertilizer, etc.

Wood fiber mulch is specifically designed for use as a hydraulically applied mulch that aids in the establishment of turf or other seeded or sprigged ground covers. As a mulching product, it conserves soil moisture, serves as an insulator against intense solar radiation, and dissipates energy from falling raindrops.

Wood fiber should be applied by a hydromulching machine (also called "hydroseeder") at rates of 1,000 to 1,500 lbs per ac. It is introduced into the slurry tank after the proportionate quantities of seed, fertilizer, etc., have been introduced. The components are agitated into a well-mixed slurry and are sprayed onto the sites or plots to be seeded. Figures 36 and 37 are photographs of wood fiber mulch in place and during application, respectively.

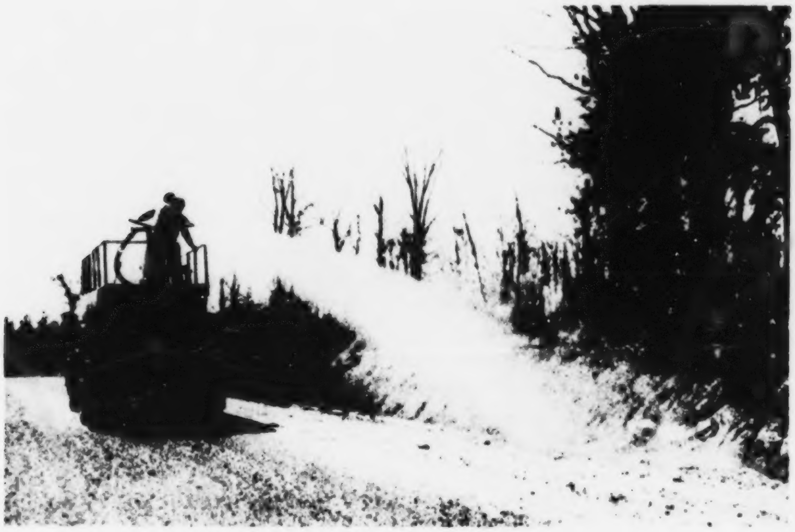


Figure 36. Hydroseeder Applying Seed, Fertilizer, and Mulch on Cut-Slope Adjacent to Newly-constructed Road (Spalding County, Georgia, Courtesy SCS, Reference 92).

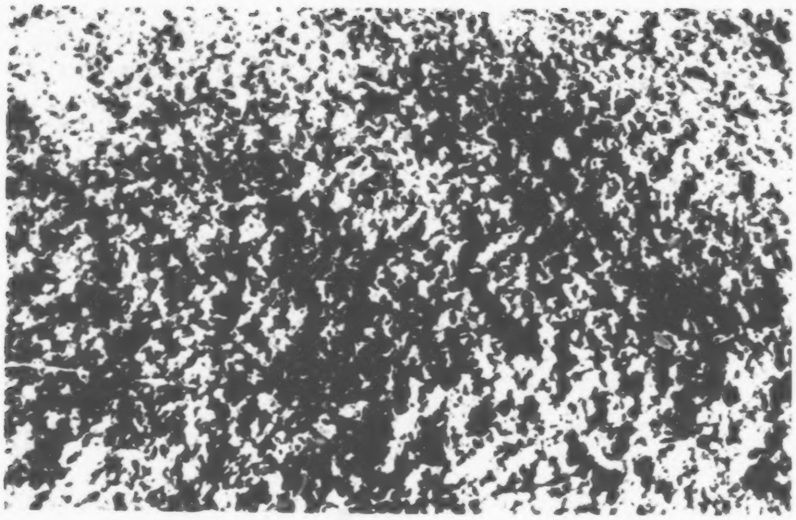


Figure 37. Wood Fiber Mulch in Place (Close-up) (Reference 120)

F. PETROSET®SB

PETROSET®SB is a chemical mulch or soil stabilizer. There are other types manufactured by other companies which also have useful applications in erosion control. Each site, situation, and chemical should be evaluated in terms of the end results desired and the relative economics of the alternatives. Figure 38 depicts the application of this material.

PETROSET® SB is a light tan colored oil in water emulsion of high strength rubber. It is free flowing and is water dispersible. The material is not flammable and is not toxic to humans or animals. In erosion control work it has the following uses:

(1) Temporary Soil Stabilization - On denuded areas it penetrates the soil and binds soil particles into a coherent mass that reduces erosion by water.

(2) Chemical Mulch - On seeded areas it penetrates the soil and binds soil particles into a coherent mass. Water and air movement into the soil is maintained.

(3) Mulch Tack - Binds natural and synthetic fiber mulches together and thereby reduces loss of mulch due to removal by wind and rain.

Numerous dilution ratios (i.e., parts of PETROSET® SB to parts of water) and application rates (also, spreading rates) have been developed by the manufacturer for different soil textures, desired penetrations, and intended usages. Practically any spraying equipment capable of delivering the desired quantity of dilute PETROSET® SB can be used. Distributor trucks with calibrated spreader bars, as well as hydroseeding equipment are suitable for applying the chemical. Thirty minutes after application this product has cured enough to perform satisfactorily and will not adhere to shoes.

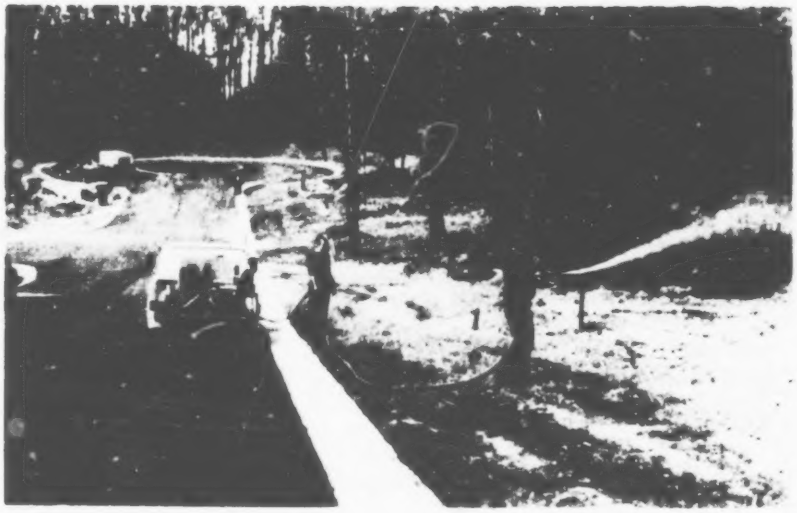


Figure 38. Chemical Soil Stabilizer Being Applied to an Area that will be Seeded at a Later Date (Reference 120)

SECTION VI

SEDIMENT REMOVAL METHODS AND COSTS

Cost estimates were made for several typical situations where sediment, which has been transported and deposited, must be removed. The basis of making these estimates generally was similar to that used for preparing the cost estimates for erosion control measures. These will be discussed and presented in subsequent paragraphs.

1. EXCAVATION OR SIMILAR METHODS OF REMOVAL

A. Street Removal

These costs apply wherever machinery, trucks, and men have ready access to the unwanted sediment deposits which could have been deposited in streets, playgrounds, parks, or similar open areas as shown by Figures 39 and 40. They represent the lower end of the range of sediment removal costs. Should access be difficult, higher costs would result. An operation of one day is assumed; and unit costs for additional days of work should not be significantly less. Work under emergency conditions, with overtime labor rates and premium equipment rental rates, will be more expensive. Appendix A presents details of the estimate.

Overall costs of about $8.00 per cy in California, and $6.60 per cy in Virginia, are indicated.

B. Basement Removal

In this situation the sediment must be removed from the basement first by hand - loading into wheelbarrows. The wheelbarrows dump onto a small conveyor, which carries the load to the street or yard where a front-end loader places it in a dump truck. Unit costs are very high.

This kind of work often is performed by owners with volunteers or low cash-cost labor, and equipment furnished in total or in part by governmental agencies. In such cases, the out-of-pocket expenditures would be less, but the true cost to the community would more nearly be represented by the figures developed by using normal labor and equipment rental rates.

Details of the estimate are in Appendix A.

Overall costs of $77.00 per cy in California, and $65.00 per cy in Virginia, have been derived.

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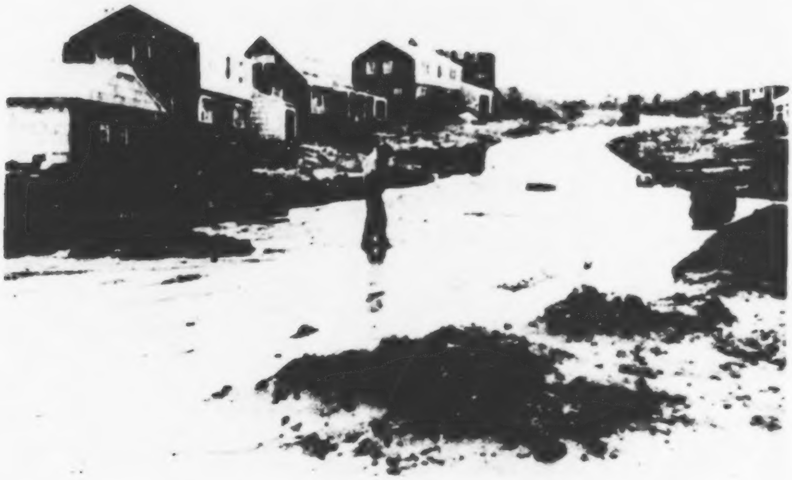


Figure 39. Erosion and Deposition of Sediment in Streets. Bowie, Maryland (Courtesy SCS, Reference 92)

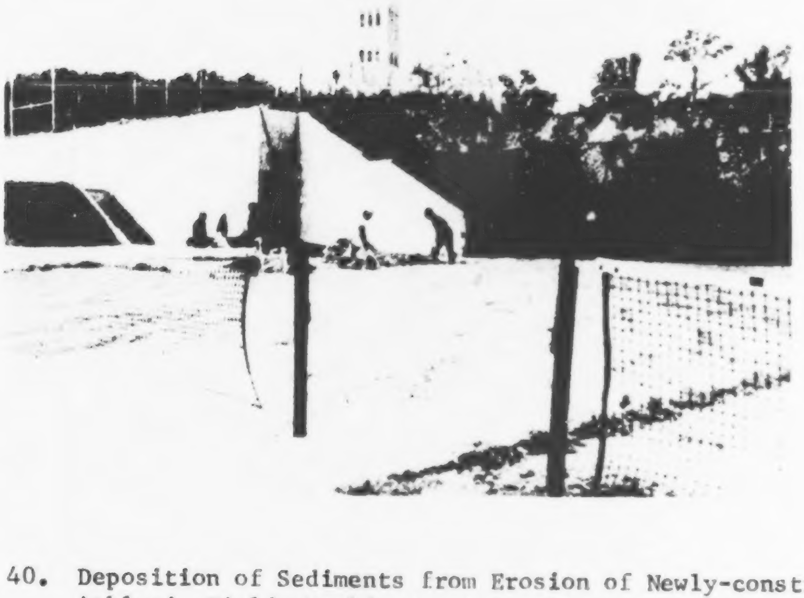


Figure 40. Deposition of Sediments from Erosion of Newly-constructed Athletic Field, Washington D.C. (Courtesy SCS, Reference 92)

C. Storm Sewer Removal

When water with a heavy sediment load flows through storm sewers, inevitably silt deposits occur as the flow decreases. Because of the possible range of degree-of-access difficulty there can be a wide range of costs. Estimates were made for two methods; one being conventional use of small dragline buckets, and the other being a newer method utilizing hydro-flushing and vacuuming.

In the latter method, special equipment first rods a clogged storm sewer using truck-supplied water under high pressure. As the debris is flushed into a nearby manhole, a large truck-mounted vacuum line and reservoir removes and stores the debris and water from the storm sewer line for later disposal.

Cost details are presented in Appendix A. It will be seen that sewer clean-out costs are very high, being around $144 per cy for the bucket-line method in California, to an estimated $68 per cy for the hydro-flush method. Virginia costs are estimated respectively at $122 per cy and $62 per cy.

D. Reservoir and Sediment Basin Removal

Figures 41, 42, 43 illustrate the varieties of sediment basins.

Possibly the greatest amount of data available on costs of sediment removal from reservoirs and debris basins has been compiled for the numerous reservoirs and basins along the foot of the San Gabriel Mountains in Southern California by the Los Angeles County Flood Control District (LACFCD). While the deposits in these facilities may be generally coarser than in many other reservoirs in the United States, the problems of excavation, hauling, and disposal are not dissimilar. The costs therefore, should be representative.

Excavation normally is by front-end loaders or power shovels. The material is carried away, by dump trucks or by belt conveyor systems, to disposal areas located varying distances from the site of excavation. Some of the disposal areas are adjacent, with very short haul distances, while others are six miles or more away. The work has been performed by Force Account and by contractors. At times the material excavated has been used for fill on another construction job, rather than being temporarily, at least, an item of waste. Because of the many variables affecting the cost in any particular instance and the great differences in amounts of material which might be required to be moved, ranging from a few hundred cubic yards to millions of cubic yards, detailed cost estimates are not being presented.

The experience in handling sediment and debris from more that 79 debris basins and 14 reservoirs, however, does provide some useful cost figures. They are summarized in the following series of numbered statements.

(1) A good average unit weight for the sediment and debris deposits in the LACFCD area is about 1.5 tons per cy. (Note: This is a higher average density than found in most reservoirs. The normal range of dry weight in situ densities is from 30 to 100 lbs per cf, equivalent to about 0.4 to 1.35 tons per cy).

(2) The average rate of sediment deposits in 14 reservoirs having a total uncontrolled drainage area of around 400 sq mi, over a number of seasons varying from 33 to 51 yrs, was about 4,900 cy per sq. mi, or about 11.5 tons per ac, per season. The low seasonal average was 2,000 cy per sq. mi and the high average was 7,000 cy per sq. mi. (4.7 tons per ac and 16.4 tons per ac, respectively). Storage capacities ranged from 150 ac ft to 53,000 ac ft.

(3) During the period 1967-70, removal costs from reservoirs ranged from $0.90 per cy to $2.40 per cy. The lower unit costs generally were for quantities of 1 to 9 million cy of material, although one job of 350,000 cy had a low cost. The higher cost jobs involved about 750,000 cy each. Both conveyor and trucks were used for hauling, and unit costs at both extremes were noted for each method.

(4) Debris basins are much smaller than most reservoirs. Their uncontrolled drainage areas varied from 0.03 sq. mi to almost 10 sq. mi. Maximum seasonal debris production generally ranged from 3,000 cy per sq. mi to 223,000 cy per sq. mi with many maximum values being in the 30,000 to 60,000 cy sq. mi range.

(5) Debris basin cleanout costs range from about $0.90 per cy to $6.60 per cy, with an average of around $2.25 per cy in Fiscal 1968-69. Costs in 1972 could be expected to be higher, due to increases in labor and equipment costs.

(6). Detailed cost breakdowns for 1968-69 debris basin cleanout jobs performed by Force Account, revealed the following for one series of jobs involving about 31 basins.

Total cy removed = 1,435,365

Cost Breakdown-Labor = 19.5%
Equipment = 78.5%
Material = 1.5%
Misc. = 0.5%

Total 100% = $2,632,700

Plus overhead and contingencies = 20% = 562,500

$3,159,200 Total Cost

Cost per cy removed = $2.20

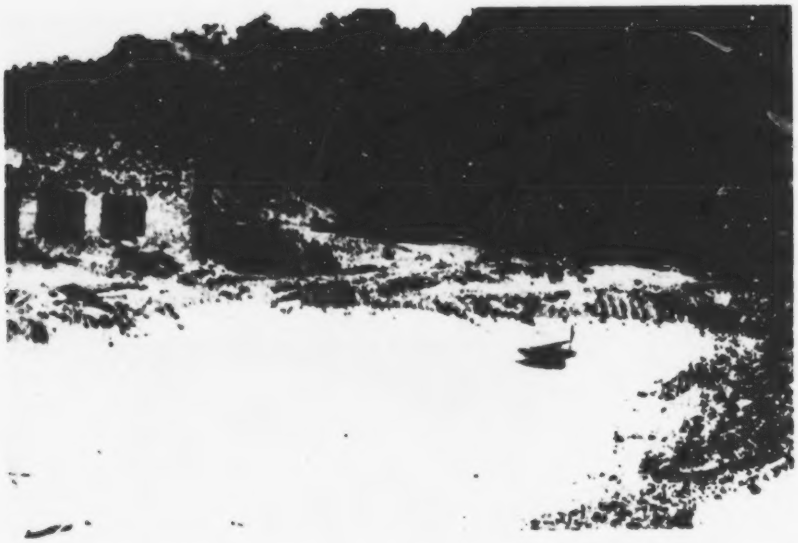


Figure 41. Small Sediment Basin with Trapped Materials (Courtesy SCS, Reference 92)

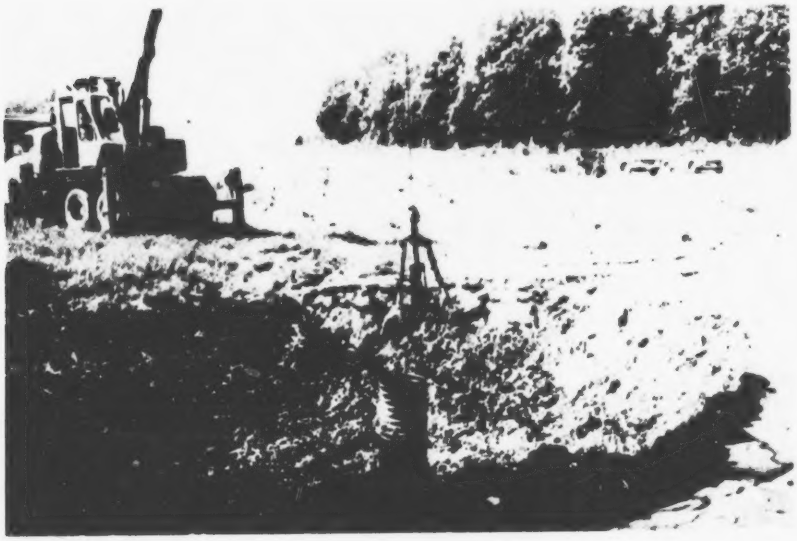


Figure 42. Accumulated Sediment Being Removed from Small Basin (Courtesy SCS, Reference 92)

Figure 43. Large Well-designed Sediment Basin in Construction Site Area for the Malibu Campus of Pepperdine University, California (Courtesy Los Angeles County Flood Control District, Reference 92)

2. REMOVAL BY DREDGING

Much of the sediment carried by streams settles in lakes, bays, estuaries, and other waterways, where it produces undesired effects. The most efficient means of removing this unwanted sediment is by dredging.

Unit dredging costs range in quoted values from $0.10 per cy to $8.00 per cy. The cost depends greatly upon the amount of material to be dredged, but even more upon the transport costs for moving the dredged material to a suitable disposal area.

Cutter-Suction dredges can range in size from small dredges having a capital cost of around $150,000, to large dredges, costing $1,000,000 or more. Large Hopper Dredges, almost exclusively owned and operated by the U.S. Army Corps of Engineers in this country, have cost as much as $17,000,000. The small dredges yield the highest unit cost per cy of material moved. The general rule is: the larger the dredge, the lower the unit cost, for the same delivery distance.

However, the larger the dredge the greater the quantity of material which must be moved to keep the costs low. Greatest efficiencies occur when the dredges can be operated around-the-clock.

Material dredged by a Cutter-Suction dredge normally is piped through a semi-flexible pipeline to a nearby disposal area. Fine sands can be pumped as far as 15,000 ft but 3,000 to 4,000 ft is a long pumping distance for gravels. Assuming fine sands are pumped about 4,000 ft, the following approximate dredging costs would result, in the San Francisco Bay Area:

Small Dredge	$0.35 - $0.45 per cy

Capacity = 200 cy per hr = 4,600 cy per day

Medium Dredge	$0.30 - $0.35 per cy

Capacity = 400 cy per hr = 9,200 cy per day

Large Dredge	$0.15 - $0.20 per cy

Capacity = 1500 cy per hr = 34,500 cy per day

The above costs assume 23 production hours in a 24-hour day.

Labor costs represent from 75 to 95 percent of the total costs. Because of differences in labor costs, similar dredging costs in the Virginia area could be about 15 to 20 percent lower. Small dredges require one man on the dredge and a pipeline crew of four men. The larger of the dredges noted above requires a dredge and boat crew of seven, plus 6 to 8 additional men on the pipeline and 2 men at the disposal area. These requirements are for an 8-hour shift.

Transport costs for greater distances increase rapidly. When the distances are too great for pumping, the material is carried by barges or in Hopper Dredges. For example, transportation of dredged material from San Francisco Bay to points 30 miles at sea adds from $6.00 to $7.00 per cy to the dredging costs.

With increased limitations on, or elimination of, disposal sites near dredging locations, overall dredging costs can be expected to increase.

It is important to note that conversion of the foregoing dredging costs per cy of material to costs per ton of dredged material required careful calculations. The weight of the solids in a cy of sediment in situ varies greatly, depending upon many variables. The usual density range of bottom sediments in reservoirs, bays and estuaries is from 30 to 90 lbs per cu ft. dry weight. Where deposits include considerable amounts of sand and gravel, densities of 100 to 120 lbs per cu ft. are common, and even higher densities are sometimes encountered.

To further complicate the situation, in situ densities often are expressed as weight including water in the voids and also expressed on a dry weight basis. Unfortunately, many articles in the technical literature do not indicate clearly which method of expressing in situ densities is presented, and the reader somehow must make certain of the basis used, or risk errors of as much as 300 percent in volume and weight calculations, in some instances.

Dredge manufacturers usually express production rates in cy per hr. where this volume represents the in situ volume of the material prior to excavation. Dredged material usually bulks (increases in volume) after excavation and occupies more space than originally occupied in situ.

3. WATER TREATMENT COSTS

The following water treatment parameters are identified as the probable major treatment costs versus suspended solids removal from raw water supplies.

(1) Degree of treatment required.

(2) Amount of chemical additions required.

(3) Sludge disposal.

A. Required Treatment Level

Generally, surface waters used for domestic water supplies will be treated by coagulation, sedimentation, and filtration. Treatment plants with coagulation-sedimentation processes are capable of treating water with a wide range of suspended solids content. If a reliable surface water supply of low suspended solids is available, however, the treatment system may consist of very simple rapid mix of an appropriate filter aid, filtration, and chlorination. Peak values of suspended solids in excess of 10 to 15 mg/l could be tolerated at infrequent intervals with a sacrifice of effluent turbidity quality.

Suspended solids in the raw water supply in amounts sufficient to require the addition of coagulation and sedimentation facilities to reduce the suspended solids to an acceptable level for filtration, will cause a jump in treatment costs due to the additional treatment step. Figure 44 illustrates the approximate capitalized and operational costs for filtration plants and for coagulation, sedimentation, and filtration facilities. The difference in these costs for a plant of a specific size would be the additional cost for up-grading a filtration plant on an annual capital and operational basis. The filtration costs are from Smith (Reference 86) and coagulation filtration costs from Koening (Reference 49).

B. Chemical Costs

Young (Reference 139) evaluated the chemical costs for water treatment against several pollution indicators. A correlation of chemical cost for certain specific pollution indicators was found; however, no chemical cost correlation was found for suspended solids removal. This seems consistent with what is known about coagulation, as the optimum coagulant dose for a water depends primarily on the chemistry of the water and, in some cases, on the nature of the suspended material, but is, more or less, independent of the amount of suspended solids present.

In a study conducted by Engineering-Science, Inc. for the United States Public Health Service, USPHS (Reference 31), coagulation experiments were made with two different clay suspensions, kaolinite and bentonite. The results of coagulation experiments at different initial suspension concentrations confirm the lack of correlation of chemical dosage on turbidity removal. A 200 mg/l kaolinite suspension demonstrated improved coagulation at a lower alum dosage than a 50 mg/l concentration. However, the 200 mg/l of bentonite suspension required a larger dosage of alum than the 50 mg/l suspension of bentonite. Thus, there seems to be no general relationships for chemical coagulation costs versus suspended solids level. However, such a relationship may exist for a specific water and specific type of suspension.

C. Sludge Disposal Costs

There is a direct relationship between the cost of dewatering and disposing of water treatment plant sludge, and the level of suspended solids in the raw water supply. The amount of sludge accumulated is proportional to the solids removed. For the purpose of estimating sludge production, it should be assumed that 100 percent of the raw water suspended solids will be removed by the treatment facility and will appear as sludge. Sludge is composed of the removed solids plus coagulation chemicals. For high concentrations of suspended solids the amount of chemicals is but a small part of the total sludge, but for low concentration levels the proportion of chemicals can be significant. In the latter cases however, the total amounts of sludge are small as compared to the amount of water treated. In view of the wide variability of available cost data, it is considered reasonable to assume that the weight of the sludge will be equivalent to the weight of the suspended solids in the raw water, for the purposes of this report only.

An AWWA Research report on "Disposal of Wastes from Water Treatment Plants Part 3" by Adrian and Nebicker (Reference 1) evaluated costs for sludge disposal from several plants and for different sludges. The disposal costs for alum sludge, for publicly-owned and operated plants, varied from a low of $2.00 per ton dry solids for lagooning to $56.00 per ton dry solids for drying on sand beds. As a general rule, the higher unit costs were for smaller installations. A model study for thickening and vacuum filtration of alum sludge projected a $122.00 per ton dry solids for disposal. Lagooning was observed to be the most widely-used process for dewatering and disposing of sludges. For the purposes of this report, the costs for the three publicly-owned alum lagoon disposal systems reported in Reference 1 will be used for the unit disposal costs. The weighted-average cost for removal of a total of about 1800 tons per year was $10.00 per ton dry solids. The low value was $2.00 per ton dry solids for a 1400 tons per year plant, and the high-value was $39.00 per ton dry solids for a 275 tons per year plant. The low cost was obtained at a plant with an annual average flow of 90 mgd and a capacity of 170 mgd, while the higher cost was experienced at a plant with an average annual flow of 9 mgd and a capacity of 20 mgd.

There are many other less definable treatment costs which may also be associated with costs due to increasing suspended solids removal; however, the costs of sludge disposal represents the major cost.

Variability of the density of sludge and the water content at the time of removal are so great as to preclude the specification of a meaningful general figure for converting tons of sludge solids to cy. Solid contents can be as low as 1.5 percent, and values of 30 percent for thickened sludge are normal. Thus each situation must be independently analyzed.

D. Summary

Three areas of possible increased water treatment costs due to increasing suspended solids in the raw water were evaluated. Two of the three general areas examined would result in increased costs. In some cases, surface water of low suspended solids content may be filtered without coagulation and sedimentation. Figure 44 illustrates the annual capital and operation cost comparison for the two treatment methods. The cost for adding coagulation and sedimentation to solve a temporary problem of excessive suspended solids will be very high when based on the tons of suspended solids removed. Expansion of a treatment facility for this purpose alone must be evaluated for the specific situation.

Increasing suspended solids in raw water already being treated by coagulation, sedimentation, and filtration will increase sludge handling costs in proportion to the suspended solids loading. No general correlation of increasing chemical costs due to suspended solids content was established; although such a correlation may be found for a specific water supply.

The principal cost increase in water treatment plants because of increased turbidity ranges from $2.00 to $56.00 per ton of dry weight of sludge, with a value of $10.00 per ton being a representative weighted-average figure for lagooning as a means of sludge disposal. These costs would pertain to publicly-owned plants containing complete treatment processes.

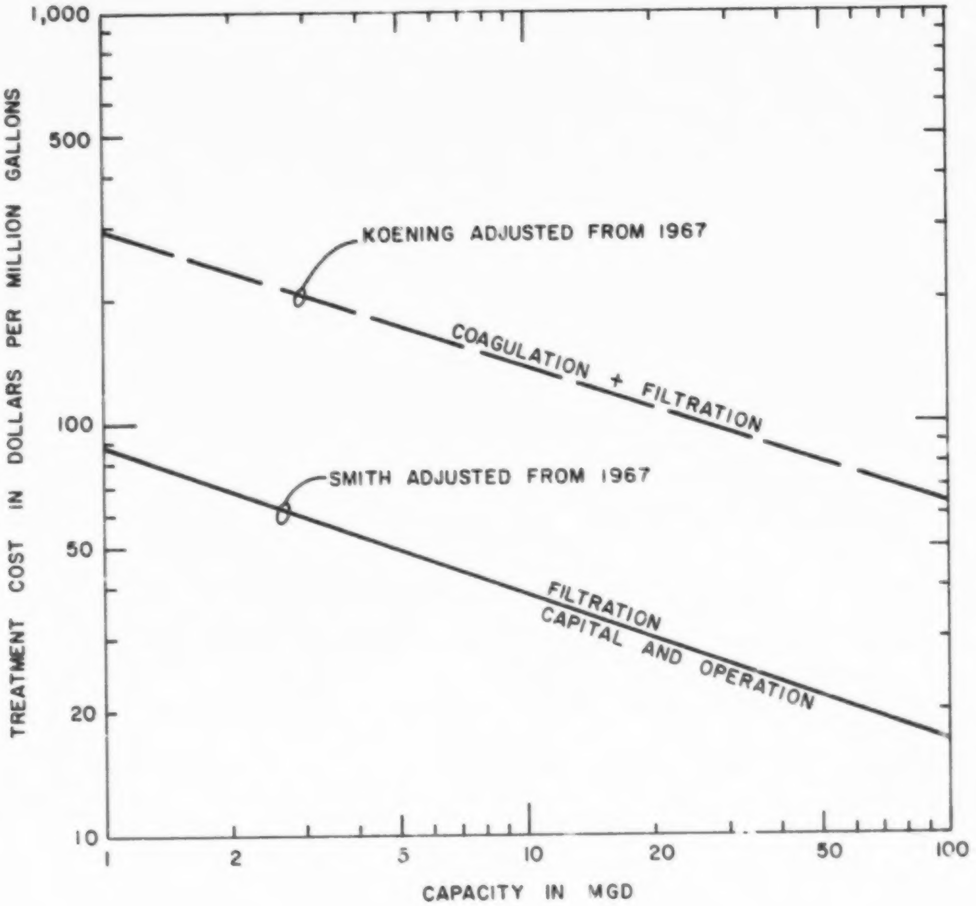


Figure 44. Treatment Costs by Filtration and Coagulation-Filtrations Includes Capital and Operational Costs (ENR Construction Cost Index 1800)

SECTION VII

ESTIMATING POTENTIAL SOIL LOSS

1. INTRODUCTION

In addition to the cost of erosion control measures, it is necessary to know how much sediment erosion is prevented by the use of control measures. Also, the amount of sediment retained on-site by the use of one or a combination of several applicable control measures should be estimable. The amount retained may be estimated as the difference between estimated soil loss without the protective measure(s) and the estimated loss with the measure(s).

Estimation of potential soil loss under a specified set of circumstances and over a particular period of time requires the use of some reasonable approach. Such an approach should incorporate, to the maximum practicable extent, present knowledge of the scientific factors involved, as well as the valuable information contained in that body of knowledge commonly referred to as the "State-of-the Art." A number of formulas have been developed for estimation of potential soil loss. None of these are completely satisfactory to experts in the soil conservation field, and efforts continue to develop better expressions for the relationships among the many complex factors which must be taken into account. For the purposes of this report it is believed that the universal soil loss equation (References 131 through 137) is the most appropriate to use.

The principal reasons for selection of the universal soil loss equation are as follows:

(1) The basic format is simple;

(2) The Equation incorporates all major factors known to influence rainfall erosion;

(3) The Equation is based on the analysis of more data than any other equation noted during the literature review aspects of the investigations which resulted in this report. More than 25 years of research and analysis work have brought the equation to its present form. During its initial development, 10,000 plot-years of runoff and soil loss data were analyzed;

(4) The principal erosion-causing factor of rainfall energy and the erosion-resistance factors inherent in the physical-chemical properties of various soils are emphasized;

(5) The Equation is basically universally applicable, whether in urban or rural areas of the world;

(6) The Equation has the flexibility to produce answers with a reasonable minimum amount of basic data and to give better answers with increased amounts of basic data;

(7) It has been used by and is currently in active use by the U.S. Soil Conservation Service in many areas of the United States; and

(8) Current research work is in progress to improve the Equation.

Principal limitations of the Equation are as follows:

(1) It is semi-empirical. While all factors included have important influences on soil loss due to erosion, the Equation does not necessarily express them in their correct mathematical relationships, and this limitation must be overcome by the selection of proper empirical coefficients.

(2) It applies only to erosion caused by rainfall of "normal" types encountered in the United States. It does not apply to erosion caused by snow-melt runoff or by very light, misty precipitation with little or no erosive energy. The Equation can be used in other areas of the world with proper modifications to fit the rainfall energy patterns prevailing, if necessary;

(3) The physical data upon which the present coefficients are based were limited to maximum uniform slopes of 20 percent and lengths of 300 feet.

(4) The Equation predicts only the soil loss from relatively small areas, and does not treat the matter of sediment deposition after leaving these areas. Thus, watershed sediment yields must be handled by other procedures. However, this limitation is not highly important for the purposes of this study, because the areas of construction sites are not large as compared to total watershed areas.

(5) Absolute soil loss values obtained from the Equation can vary from actual occurrences because of deficiencies in data and in the presently available coefficients. Hence, the Equation is more accurate as an index to compare relative erosion under specific circumstances.

(6) Because of the complexity of the phenomena involved, it is most valuable when interpreted by qualified experts.

Application of the universal soil loss equation is outlined in the remainder of this section. The best summary of the method is presented in Reference 136. That reference, however, limits applications to croplands east of the Rocky Mountains. Subsequent developments, including some of the hydrologic analyses summarized in Appendix B of this report, extend the applications to the entire country.

2. THE ARS "UNIVERSAL SOIL LOSS EQUATION."

The universal soil loss equation developed by the Agricultural Research Service is a semi-empirical predictive relationship between the mass of soil-loss per unit area and all major factors known to influence rainfall erosion. It has the form:

$$A = RKLSCP \tag{1}$$

where: A = the computed soil loss in tons (dry-weight) per acre from a given storm period;

R = the rainfall erosion index for the given storm period in units of ft-ton in: per acre-hr (described further below);

K = the soil erodibility value, defined as the erosion rate in tons per acre per unit of R for a specific soil in continuous fallow condition on a 9 percent slope having a length of 72.6 ft;

L = the slope length factor, defined as the ratio of soil loss from a specific field to that from a unit field having the same soil type and slope but with a length of 72.6 ft;

S = the slope factor defined as the ratio of soil loss from a specific field to that from a similar field but having a 9 percent gradient;

C = the cropping management factor defined as the ratio of soil loss from a field with specified cropping and management to that from the same field but under fallow condition, and;

P = the erosion control practice factor defined as the ratio of soil loss with a given practice (contouring, strip-cropping, or terracing) to that with straight-row, up-and-down slope farming.

Applications of the full Equation are given in Section VIII, Basin Selection and Evaluation. Each of the factors defined above are discussed in the following pages of this Section.

A. R, Rainfall Factor

The rainfall factor, R, also known as the rainfall erosion index, is defined for a single storm as:

$$R = \frac{EI}{100} \tag{2}$$

where: E = the total kinetic energy of a given storm in ft-tons per ac and I is the maximum 30-minute rainfall intensity for the area in inches per hr.

The rainfall factor is thus a composite term, representing the effects of raindrop impact for the entire storm duration and maximum rainfall intensity. It can be expressed as a function of rainfall intensity alone. The records of individual storms are summed over a given time interval to obtain cumulative R-values for other periods of time, such as for a month or a year. The annual R factors for approximately 2,000 locations in the United States have been summarized in the form of "iso-erodent" maps (Reference 136). Figure 45 shows an example of these maps. The same publication also provides data for estimating monthly soil loss in the eastern United States, and expected magnitudes of single-storm erosion index values for various return periods.

For comparing the effects of different conservation measures on construction sites it is necessary to be able to estimate potential soil-loss values for an entire range of periods of time, ranging from individual storms to annually. A recent SCS publication (Reference 105) provided clues which led to the development of generalized equations for determination of the rainfall erosion index. This development is summarized in Appendix B of this report; however, the essential results are set forth in this Section for use with the soil loss equation.

SCS studies have shown that the time distribution of rainfall in the United States can be represented adequately for many purposes by the two curves shown in Figure 46. Reference 105 by the SCS also presented a graphical relationship between Type II 2-yr frequency, 6-hr duration rainfall and the Annual rainfall erosion index. This is shown in Figure 47 together with a similar curve for Type I rainfall developed by this study from basic ARS, SCS, and USWB data cited in Appendix B. Thus, the Annual rainfall erosion index can be obtained from the graph by entering with the 2-yr, 6-hr rainfall for the location under study. The latter values are presented on maps such as Figure 48, or may be developed independently from basic local data.

Using Figure 48 as a base, and the curves of Figure 47, the iso-erodents of Figure 49 were prepared. The extremely close correlation to the original iso-erodents presented in Figure 45 can be observed.

The rainfall erosion index for individual storms can be obtained from either Figure 50 or 51.

B. Summary Procedures for Estimation of Rainfall Erosion Index

(1) Example I - Rainfall Erosion Index for a 2-yr 6-hr Storm

This storm can be considered to be a typical "average" storm, because it can be expected to occur 50 percent of the time, and the 6-hr duration has been found by SCS to be the most frequently occurring storm length.

(a) Locate the area under study on a chart in USWB TP No. 40 (or similar publication) similar to Figure 48.

(b) Determine the value of the 2-yr 6-hr rainfall from the preceding chart.
(c) Check as to the zone (Zone I or Zone II) in which the area under study is located.
(d) Use the graph in Figure 50, or Figure 51 to arrive at the erosion index, using the 6-hr duration line.

Examples:
Walnut Creek Drainage Basin, California. (Zone I) From USWB TP 40, the 2-yr 6-hr rainfall is given as 1.5 inches. Therefore, the erosion index for this storm duration is found from Figure 50 to be 12.
Occoquan Drainage Basin, Virginia (Zone II) From USWB TP 40, the 2-yr 6-hr rainfall is given as 2.55 inches. The erosion index for this storm is found to be 66.

(2) Example II - Rainfall Erosion Index for Storm of Any Duration Up to and Including 24-hr for 2-yr Frequency.
The same procedure as for Example I may be used except that the chart used from USWB TP 40 will be the one for the storm frequency and duration desired.

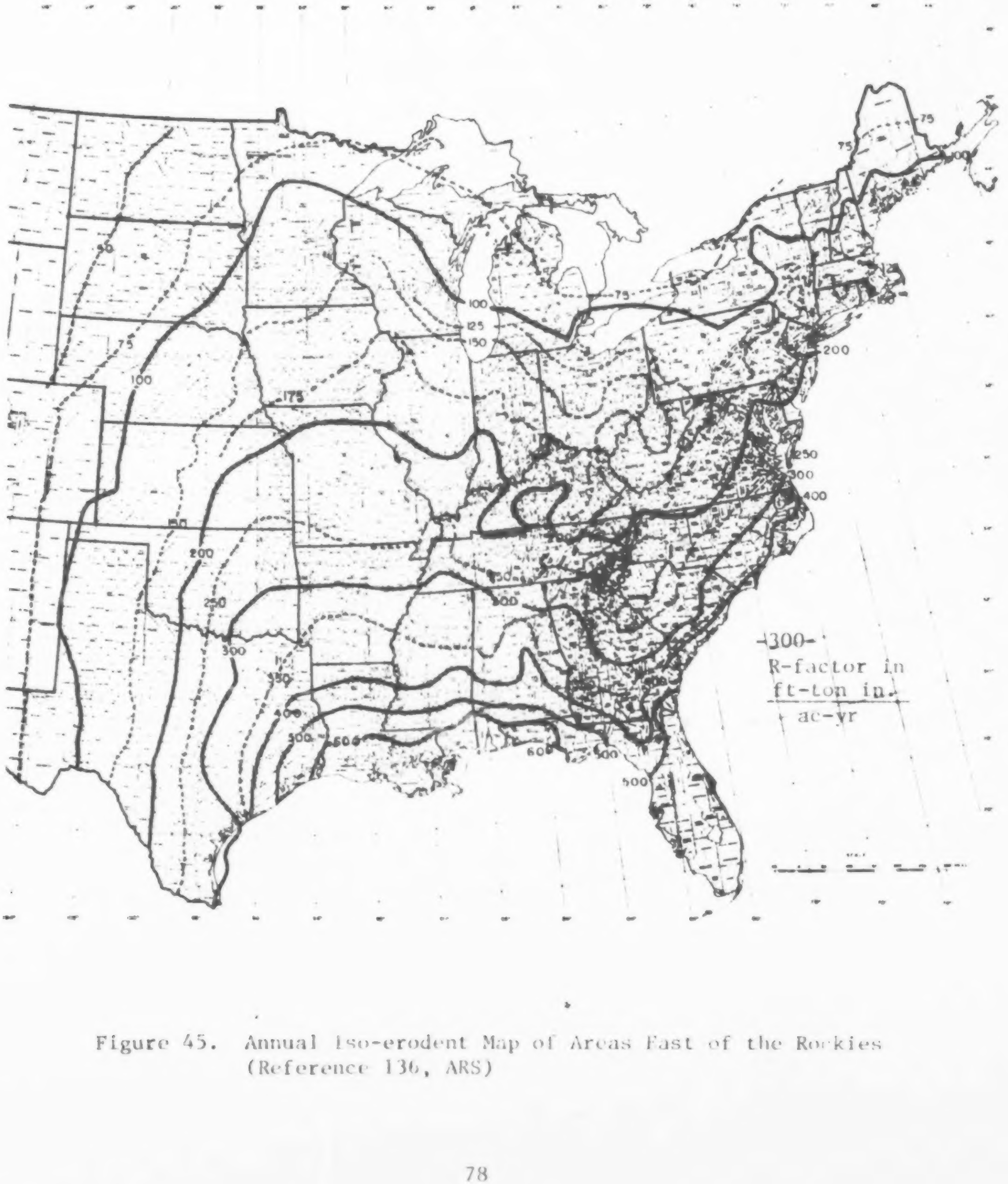
(a) The graph in Figure 50 or Figure 51 is used to arrive at the erosion index using the appropriate depth of rainstorm and duration hour line.

Example:
Determine the erosion index for a 24-hr storm with a 2-yr frequency in the vicinity of Occoquan. United States Weather Bureau (USWB) TP 40 shows depth of precipitation for such a storm to be 3.40 inches. Area is in Zone II. The estimated erosion index from Figure 51 is 65.

(3) Example III - Average Annual Rainfall Erosion Index

(a) Locate the area under study in a chart in USWB TP 40 (or similar publication).
(b) Determine the value of 6-hr rainfall for a 2-yr frequency.
(c) Check as to the Zone in which the area is located.
(d) Obtain the Average Annual Erosion Index from Figure 47.

Example:
Determine the 2-yr frequency annual erosion indices for the Walnut Creek, California and Occoquan River, Virginia, areas.
Walnut Creek: 2-yr 6-hr rainfall, Type I = 1.5 in. Average Annual Erosion Index = 40
Occoquan River: 2-yr 6-hr rainfall, Type II = 2.55 in. Average Annual Erosion Index = 210



75
100
125
150
175
200
250
300
350
400
500
600
300
R-factor in
ft-ton in.
ac-yr

Figure 45. Annual Iso-erodent Map of Areas East of the Rockies (Reference 136, ARS)

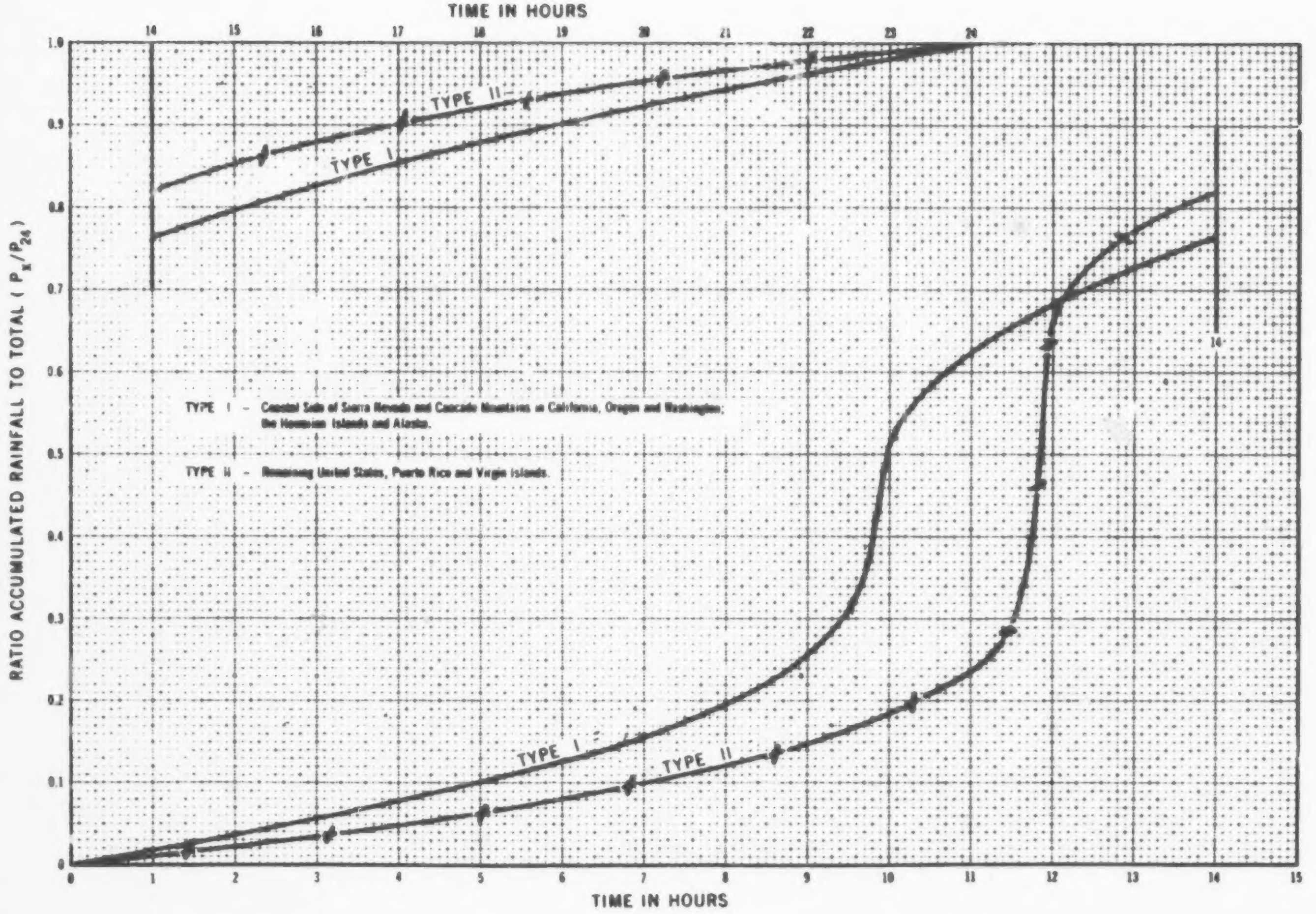


Figure 46. Time Distribution of the Dimension Less Rainfall Depth for Two Storm Types (Reference 104, SCS)

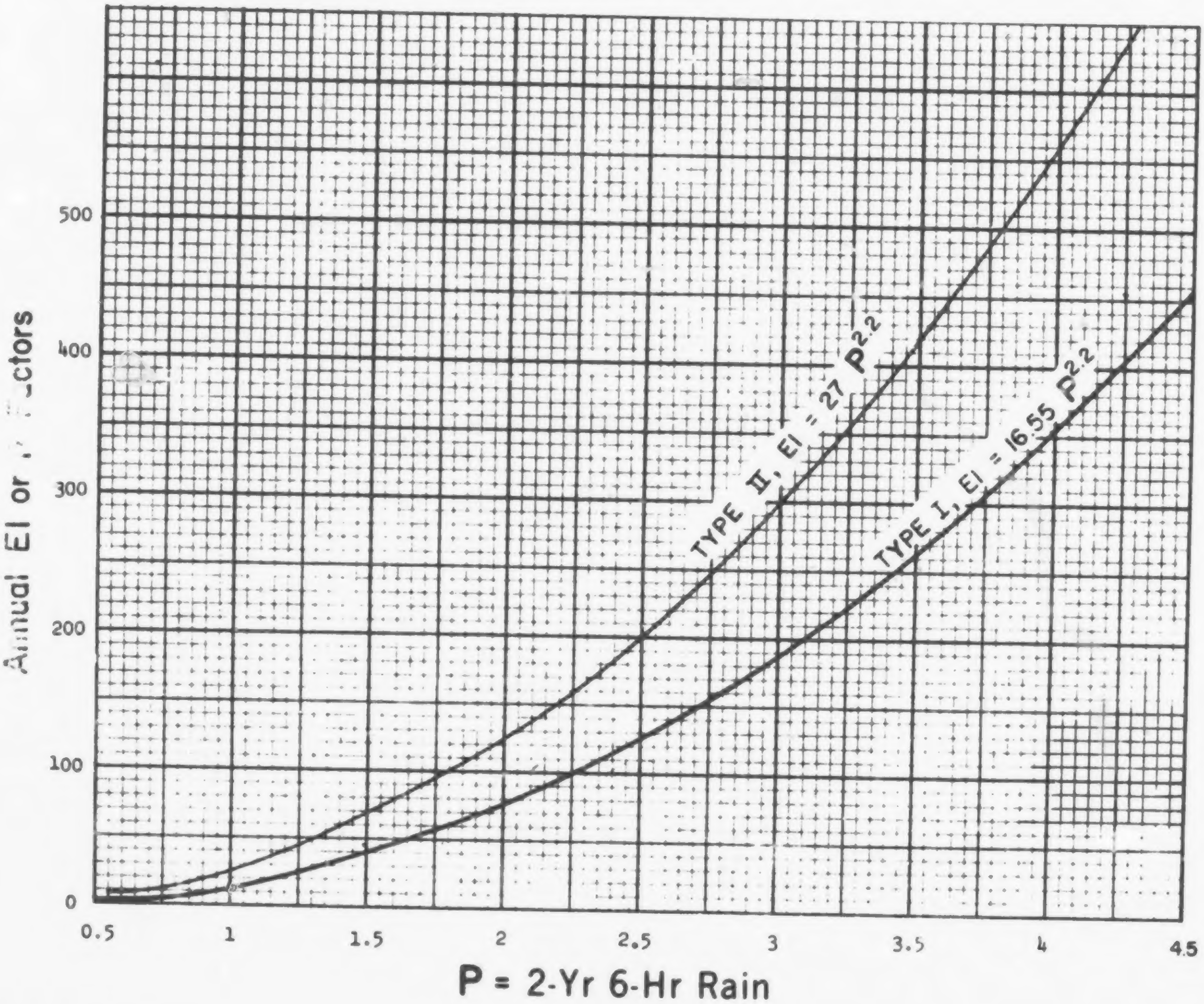


Figure 47. Relation Between Annual Average Erosion Index and the 2-yr 6-hr Rainfall Depth for Two Rainfall Types

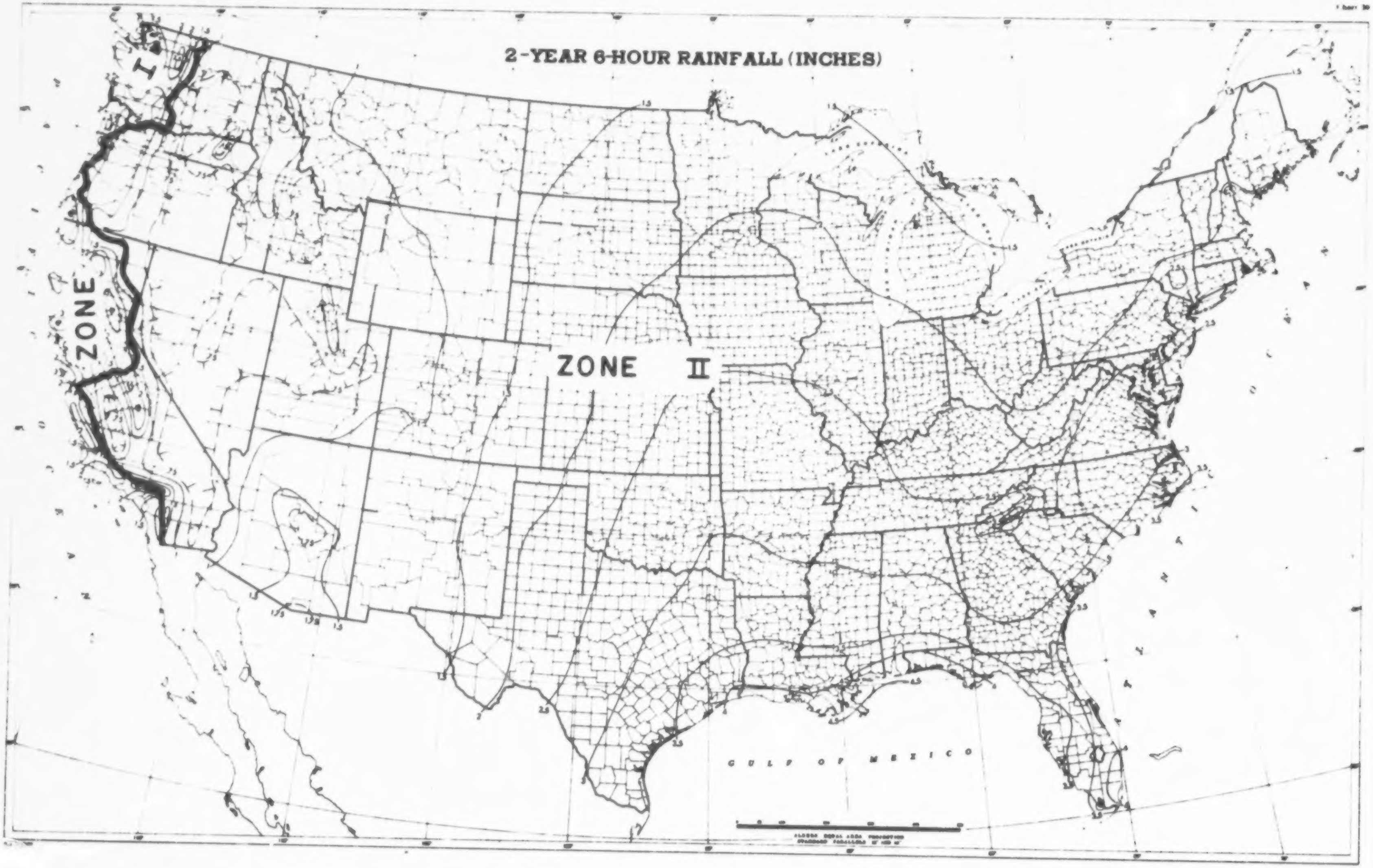

2-YEAR 6-HOUR RAINFALL (INCHES)
ZONE I
ZONE II
GULF OF MEXICO

Figure 48. Depths of the 2-yr 6-hr Rainfall, Inches, in Various Parts of The United States (Reference 123, 124 USWB)

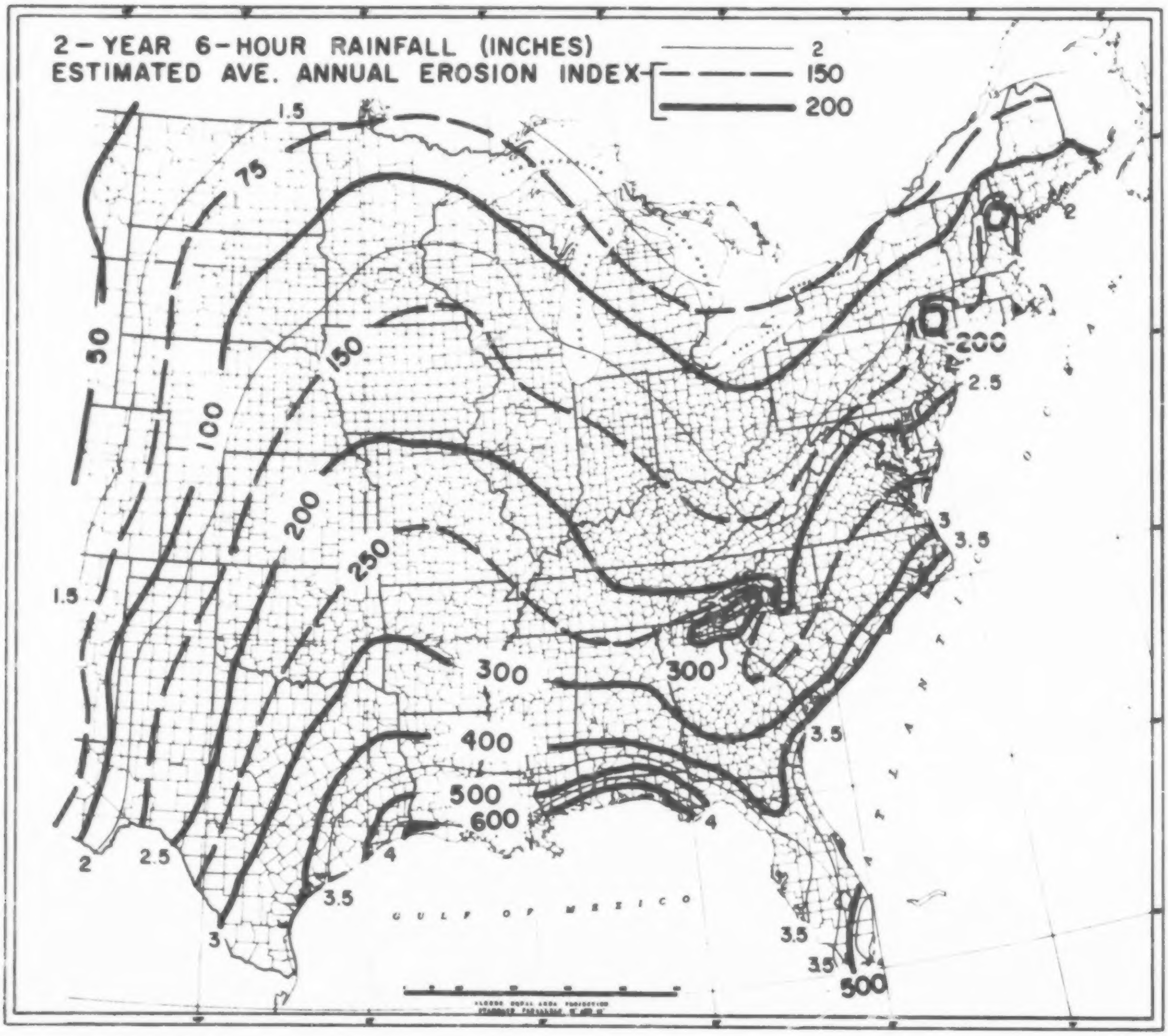

2-YEAR 6-HOUR RAINFALL (INCHES)
ESTIMATED AVE. ANNUAL EROSION INDEX
2
150
200
1.5
75
50
100
150
200
250
300
300
400
500
600
1.5
2
2.5
3
3.5
4
4
3.5
3.5
500
2
200
2.5
3
3.5
3.5
GULF OF MEXICO

Figure 49. Iso-erodent Map Derived from 2-yr, 6-hr Rainfall Map. Superimposed for Area East of the Rockies.

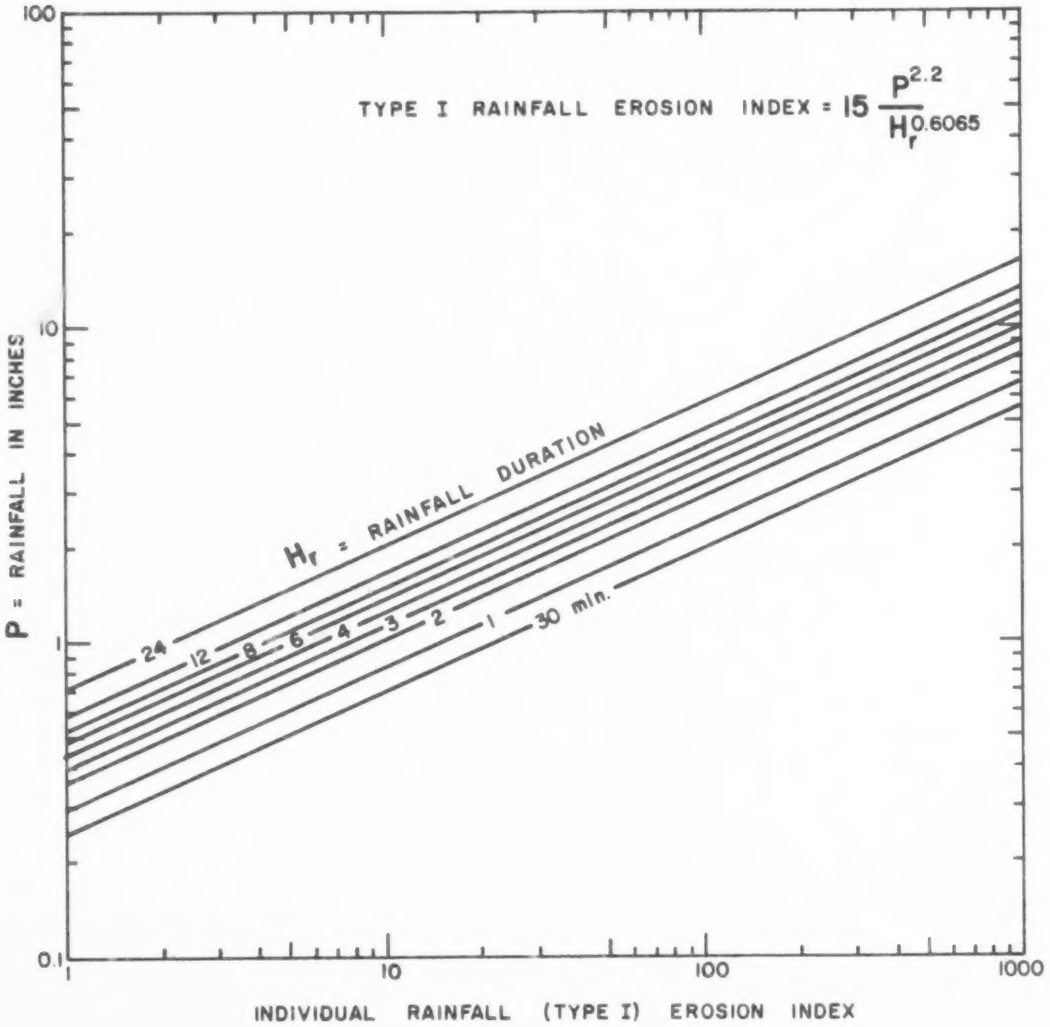


Figure 50. Relation Between Depths and Duration of Type I Rainfall and Single Storm Erosion Index. 2-yr Frequency of Occurrence

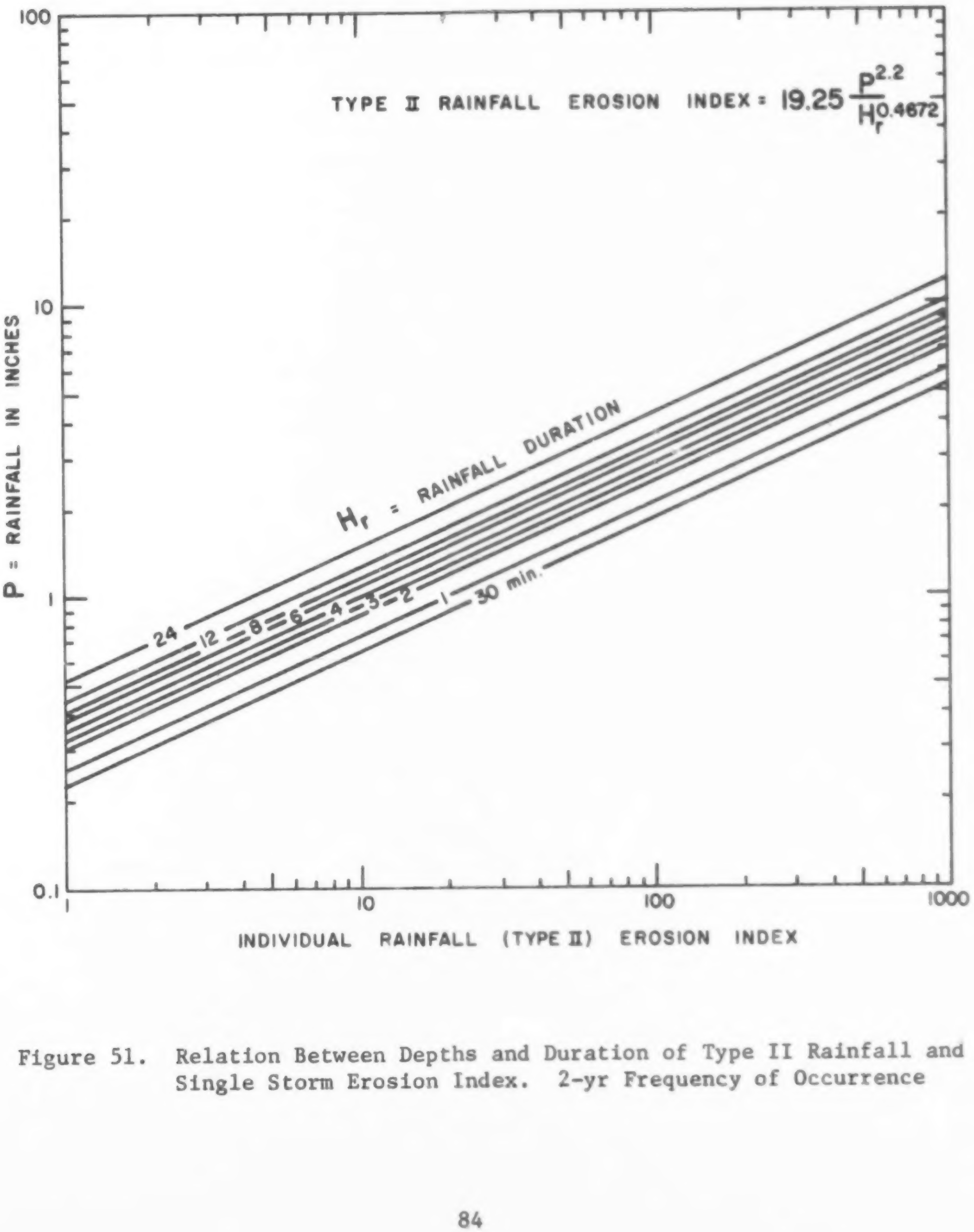


Figure 51. Relation Between Depths and Duration of Type II Rainfall and Single Storm Erosion Index. 2-yr Frequency of Occurrence

C. K, Soil Erodibility Factor

The soil erodibility factor, K, represents the intrinsic erodibility of the soil and is determined experimentally as the ratio of erosion per unit of R from a unit plot on a particular soil. (A unit plot is 72.6 ft long, has a uniform slope of 9 percent, is kept in continuous fallow condition and is tilled for a period of at least 2 years or until prior crop residues have decomposed). When all the conditions of a unit plot are met, each of the factors, L, S, C, and P equal unity and K equals A/R.

K-values for 23 bench-mark soils, from which erosion has been experimentally measured since 1930, have been identified (Reference 136) and are listed in Table 3.

Wischmeier et al. (Reference 137) recently reported a new soil particle-size parameter which can be used to derive a convenient erodibility equation that is valid for exposed subsoils as well as farmland. A simple nomograph (Figure 52) provides quick solutions to the equation. Only five soil parameters need to be known: percent silt, percent sand, organic matter content, structure, and permeability.

Entry values for all the nomograph curves, except the permeability class, are for the upper 6 or 7 in. of soil. For scalped soils, this layer would constitute newly exposed horizons.

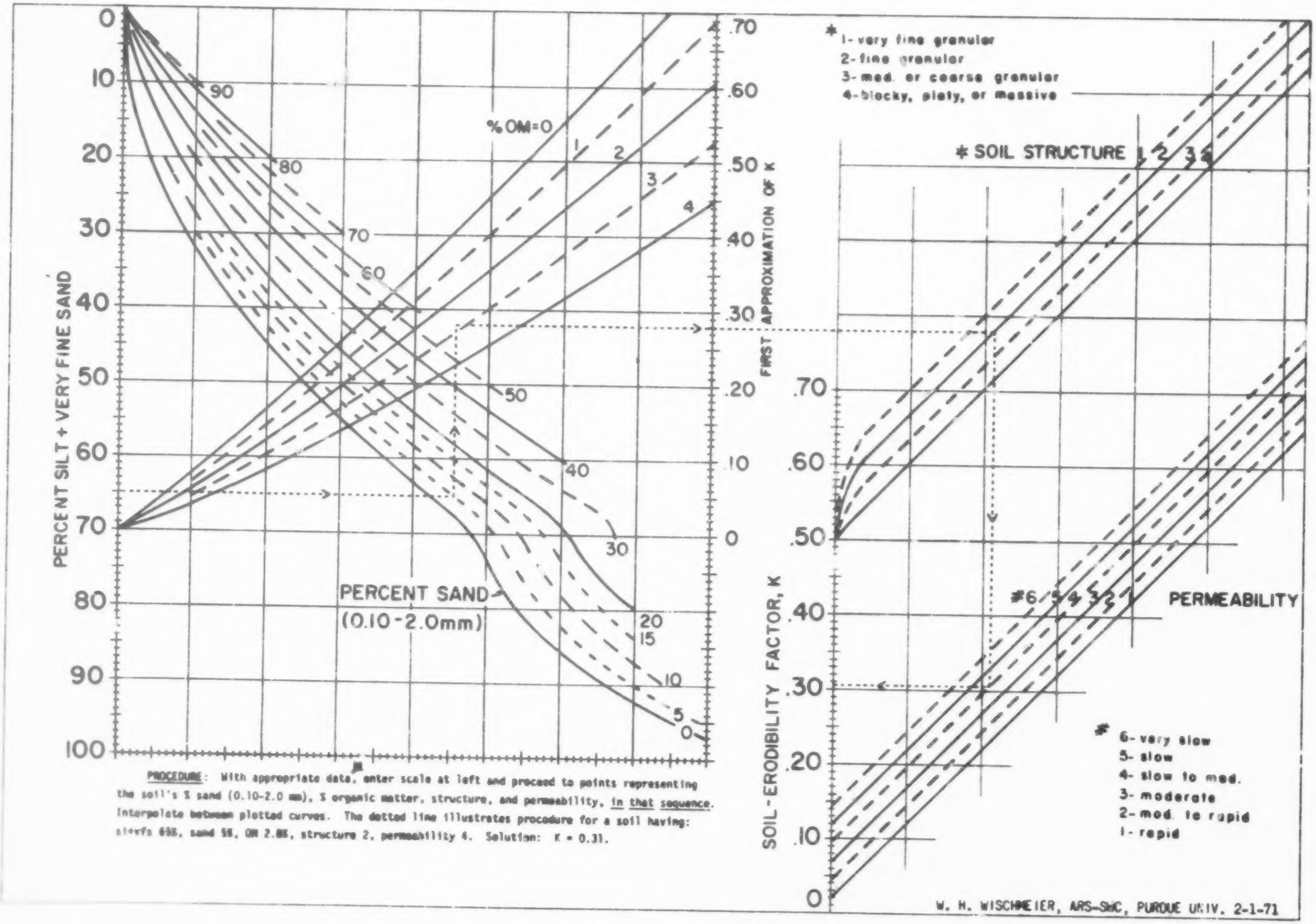
TABLE 3

K-VALUES OF 23 BENCH-MARK SOILS*(1)

Soil	Source of Data	Computed K
Dunkirk silt loam	Geneva, N.Y.	0.69(2)
Keene silt loam	Zanesville, Ohio	.48
Shelby loam	Bethany, Mo.	.41
Lodi loam	Blacksburg, Va.	.39
Fayette silt loam	LaCross, Wis.	.38(2)
Cecil sandy clay loam	Watkinsville, Ga.	.36
Marshall silt loam	Clarinda, Iowa	.33
Ida silt loam	Castana, Iowa	.33
Mansic clay loam	Hays, Kans.	.32
Hagerstown silty clay loam	State College, Pa.	.31(2)
Austin clay	Temple, Tex.	.29
Mexico silt loam	McCredie, Mo.	.28
Honeoye silt loam	Marcellus, N.Y.	.28(2)
Cecil sandy loam	Clemson, S.C.	.28(2)
Ontario loam	Geneva, N.Y.	.27(2)
Cecil clay loam	Watkinsville, Ga.	.26
Boswell fine sandy loam	Tyler, Tex.	.25
Cecil sandy loam	Watkinsville, Ga.	.23
Zaneis fine sandy loam	Guthrie, Okla.	.22
Tifton loamy sand	Tifton, Ga.	.10
Freehold loamy sand	Marlboro, N.Y.	.08
Bath flaggy silt loam with surface stones > 2 inches removed	Arnot, N.Y.	.05(2)
Albia gravelly loam	Beemerville, N.J.	.03

(1) *Reference 186

(2) Evaluated from continuous fallow. All others were computed from row-crop data.



PROCEDURE: With appropriate data, enter scale at left and proceed to points representing the soil's % sand (0.10-2.0 mm), % organic matter, structure, and permeability, in that sequence. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: si+vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: K = 0.31.

Figure 52. Nomograph for Estimating K-Values of Soils (Reference 137)

D. L, Slope Length, and S, Slope Factors

Although the effects of slope length and steepness on soil loss were investigated separately, they are usually combined in a single factor, LS. This factor is the ratio of soil loss per unit area from a given field to that from the unit plot having a 9 percent slope and 72.6 ft length. The combined LS factor can be computed from an empirical equation, which is shown graphically in Figure 53 (Reference 105).

The length times slope product (otherwise knows as topographic factor, LS) has been extended (Reference 105) to cover lengths up to 1,600 ft and for slopes up to 50 percent (equivalent to 2H:1V). Figure 54 shows extensions of the slope effect chart beyond the 800-ft slope length. Slopes commonly used by highway engineers have been added onto the original curves. These extensions are indicated as being extrapolations beyond the range of confirmed data. Therefore, they should be recognized as speculative estimates. Extrapolated values for slopes of 4:1, 3:1, 2:1, and 1:1 have been added to the SCS graph.

E. C, Cropping - Management Factor

The cropping-management factor, C, is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from tilled, continuous fallow conditions. The C-factor thus reflects the combined influence of crop type and crop rotation pattern. The value of C is tabulated in Reference 136 according to crop type and sequence, residue management practice, and crop productivity level. Factors such as seasonal distribution of rainfall, dates of plowing, seeding, and harvesting, and methods of seeding and tilling must also be considered in computing C. The method of establishing base values for the cropping-management factor by controlling selected variables in the soil loss equation is described in Reference 132 (Equation 1).

F. P, Erosion Control Practice Factor

The erosion control practice factor, P, is a parameter representing the reduction in soil loss resulting from soil conservation measures such as contour tillage, contour stripcropping, terracing, and stabilized waterways. Values of P range from 0.90 for contouring on steep slopes (18 to 24 percent) to 0.25 for contour stripcropping on gentle slopes (Reference 136). The effect of terracing is the reduction of the length of slope from that of the entire field to the horizontal distance between terraces. The methods of determining P for a given conservation practice and, alternatively, the selection of a conservation practice, using the soil loss equation, have been described in Reference 136.

Revised values of erosion-control practice factor are listed in Reference 105 for given range groupings of land slope between 2 percent and 24 percent for contouring, contour stripcropping, and terracing.

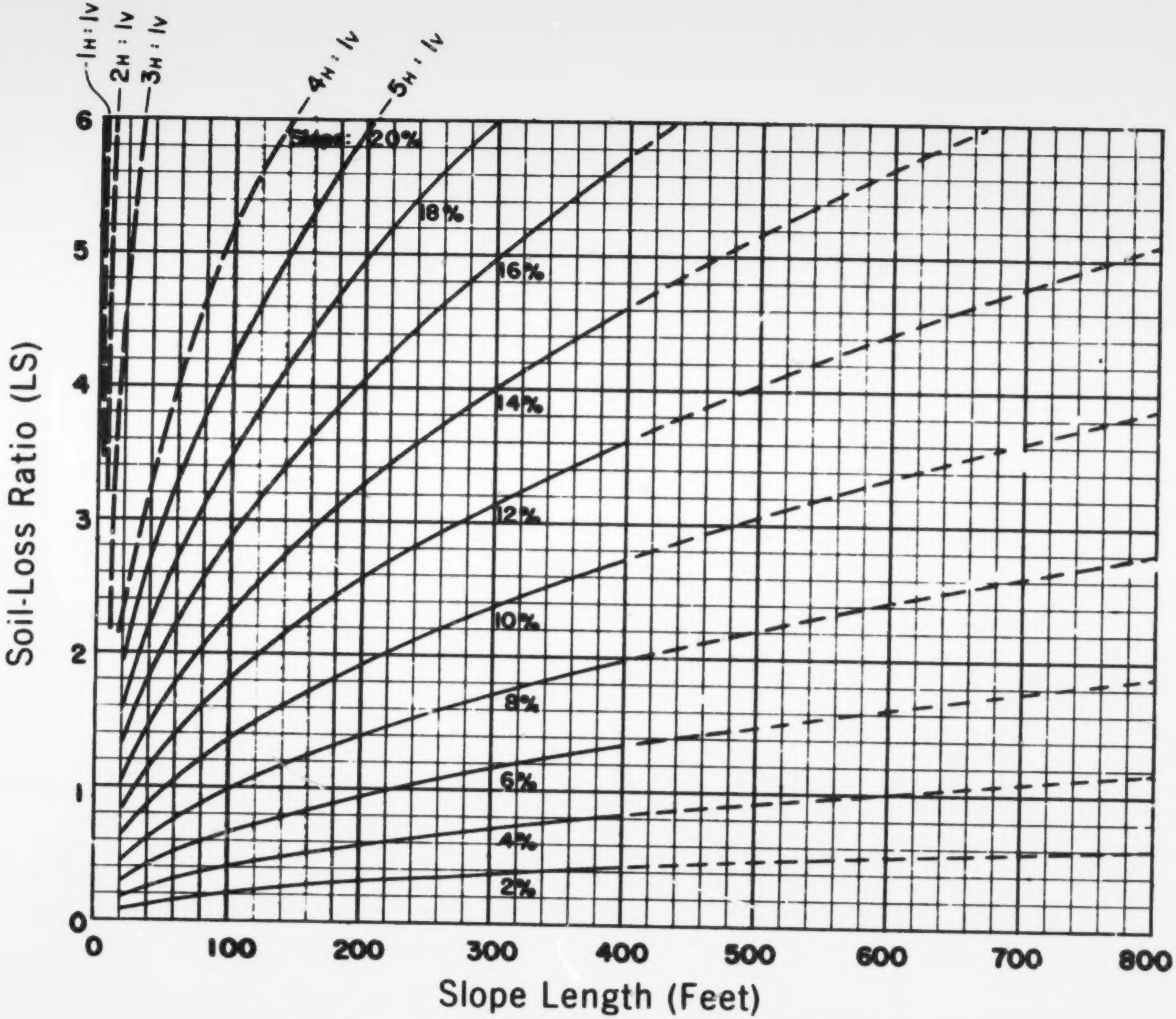


Figure 53. Slope-Effect Chart (Topographic Factor, LS Modified from Reference 105)

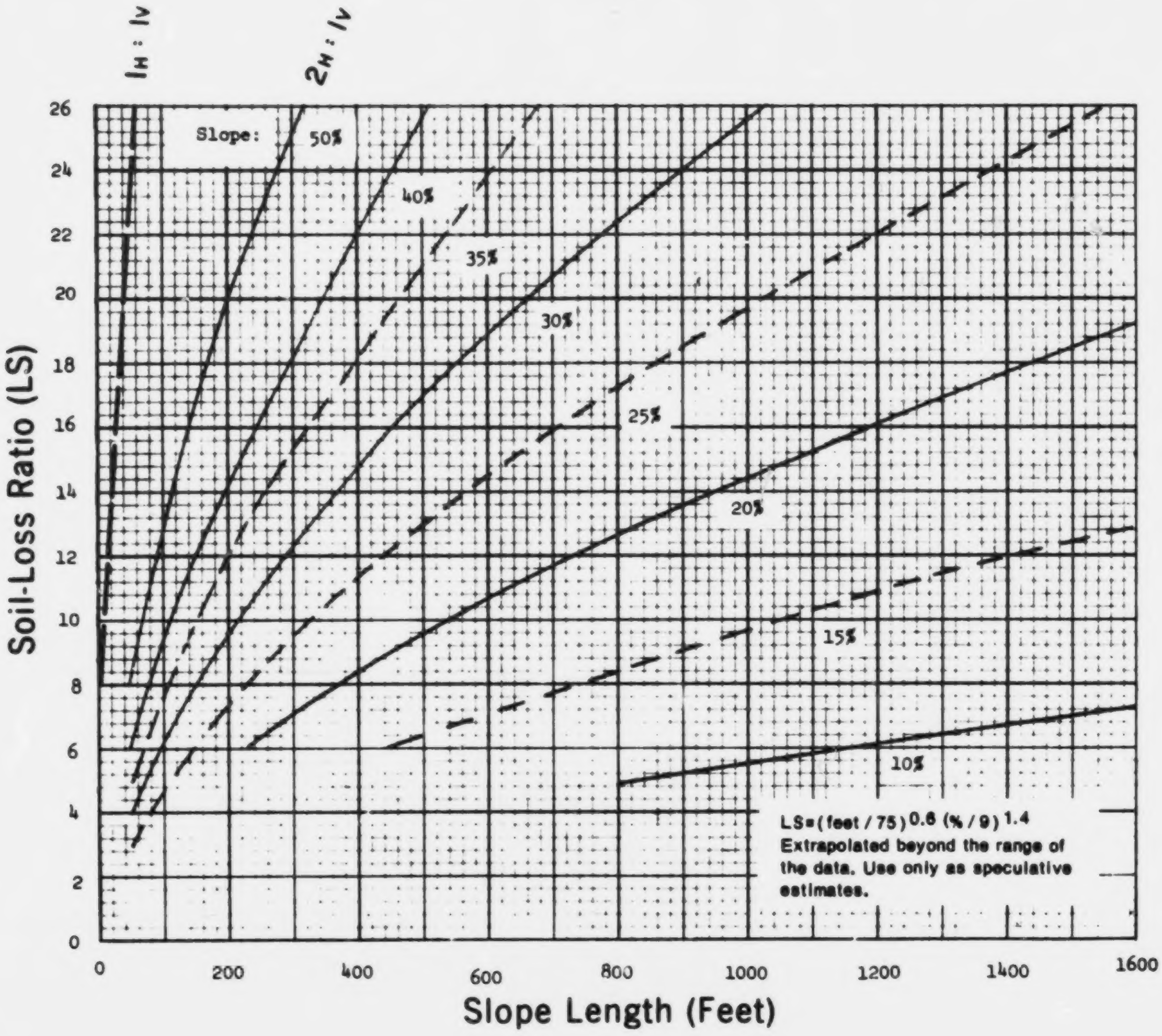


Figure 54. Extensions to the Slope-Effect Chart (Topographic Factor, LS) (Modified from Reference 105)

3. PREDICTING WATERSHED SEDIMENT YIELDS

Though related to erosion, sediment yield from a watershed is seldom equal, quantitatively, to the rate of erosion on the watershed, the difference being because of deposition of material between the points of erosion and measurement downstream. The parameter commonly used to describe this process is the sediment delivery ratio, which is the percentage relationship between the average annual sediment yield at a specified measuring point and the average annual gross, or total, erosion occurring in the watershed upstream from that point.

A knowledge of the sediment delivery ratio is very useful in planning a wide variety of water utilization and control structure such as dams, diversion channels, and debris basins. Several investigators have tried to correlate delivery ratio with various watershed physiographic factors (References 26, 27, 64, 74 and 130). The investigators generally agree that the sediment delivery ratio decreases with increasing drainage area in a basin that is relatively homogeneous. However, many authors also agree that annual delivery ratios are also greatly affected by climate and rainfall patterns. The validity of using a particular delivery-ratio relationship beyond the physiographic province for which is was developed is dubious. Until higher levels of competency are achieved for estimating sediment delivery ratios the curves or equations available at present should be used with the knowledge that they are, at best, approximations. In Reference 130 it is pointed out that soil loss does not have a strictly linear relationship with the rainfall erosion factor R, as predicted by the universal soil loss equation. In some cases examined, the equation over-estimated sediment production for years with high R values.

Considering the present state of knowledge of sediment delivery ratios, and the fact that construction sites are relatively small compared to agricultural and total watershed areas (ranging to size from less than 5 ac to about 500 ac) the sediment delivery ratio, for the purposes of this study, has been assumed to be 100 percent. This is believed to be a reasonable, generally conservative, assumption. The assumption is, thus, that all sediment eroded will leave land surfaces in the construction sites and will arrive at runoff channels, streets, ponds, or at other places either within or below the site. Stated another way, the total soil loss predicted by the universal soil loss equation is assumed to be the amount of sediment which will eventually be deposited in a place in which it is unwanted, either on or off the site.

4. RESERVOIR TRAP EFFICIENCY

When a sediment retention basin is to be built on a site, its trap efficiency must be taken into consideration in evaluating sediment yields. A very small reservoir will not be as efficient as a very large one in trapping sediment, however, at the same time, a large reservoir would entail considerably greater costs.

A valuable guide for predicting the trap efficiency of medium and larger reservoirs has been established (Reference 9). Some work has been done (Reference 67) on evaluating the trap efficiency of small reservoirs, debris basins, and debris dams. However, prediction guides are still inadequate and a complete study of the rate of sediment deposition in a particular reservoir is usually required for accurate results. Such studies would indirectly yield data on loss of storage capacity in reservoirs under question.

Figure 55 presents a curve showing the capacity/annual inflow ratio of a reservoir versus sediment trap efficiency in percent. When the ratio is 0.01 such a small reservoir will trap about 45 percent of the sediment in the inflowing waters. Increasing the size of the reservoir ten times i.e., to a ratio of 0.1, will increase its efficiency to about 85 percent. Further increase in size of reservoir to a ratio of 1 will improve sediment removal efficiency up to 92 percent. Thus the law of diminishing returns applies, whereby increased extraction of the sediments becomes economically unjustifiable beyond a certain limit.

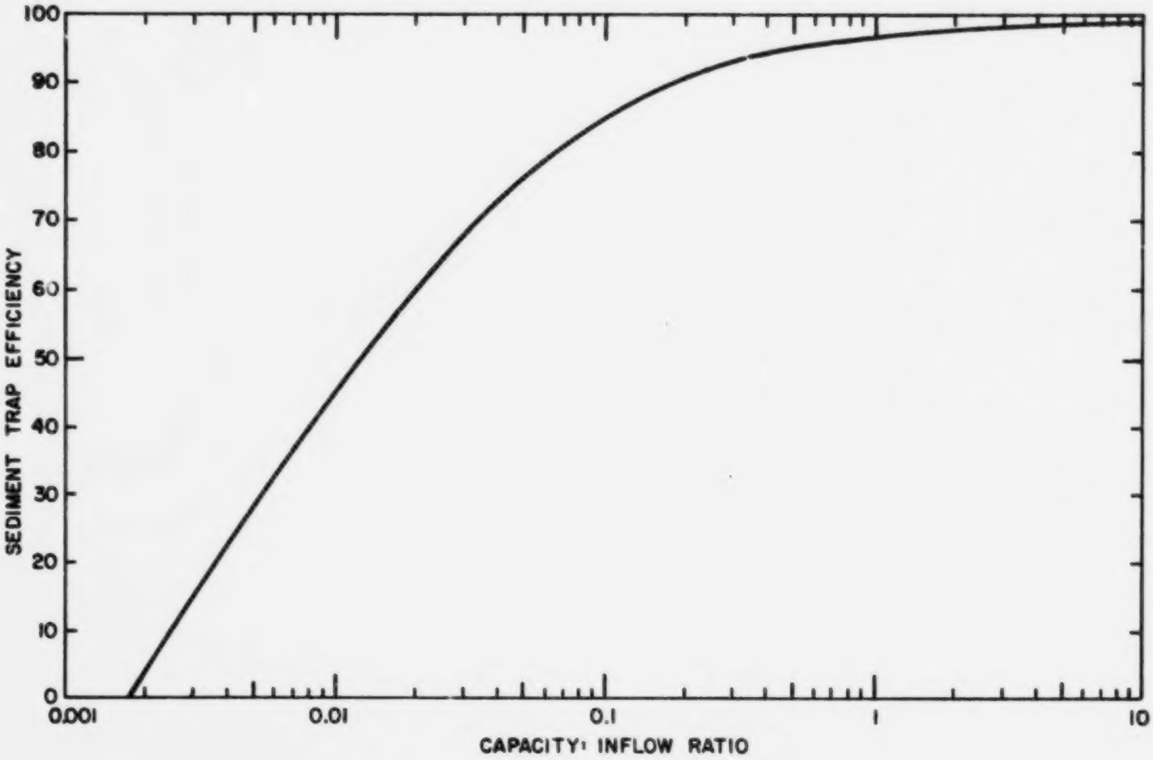


Figure 55. Relationship Between Capacity/Inflow Ratio and Sediment Trap Efficiency of Reservoirs

SECTION VIII

EFFECTIVENESS OF EROSION AND SEDIMENT CONTROL MEASURES

The effectiveness of some individual components of erosion and sediment control methods can be found in published data (Reference 24, 107) but little information is available on the various treatment combinations. (Reference 26). Furthermore, effectiveness factors have been derived for agricultural practices and cannot always be assumed equivalent to urban construction effectiveness. A method has been developed for estimating effectiveness of individual and systems erosion and sediment control methods (Reference 26), and is described herein.

1. CALCULATING PERCENT EFFECTIVENESS

The various individual treatments may be viewed as cropping-management (C) and conservation practice (P) factors for reducing soil losses. Thus, the soil loss (A_1) from a given construction site having erosion and sediment control treatments is computed by the universal soil loss equation:

$$A_1 = RLSKCP \qquad (1)$$

If the same construction site was denuded and employed no erosion and sediment control treatments, the soil loss (A_2) would be:

$$A_2 = RLSK \qquad (2)$$

since the factor C and P values equal 1.0. Values for RLSK are equivalent in Equations (1) and (2) since the same construction site is used for both equations. The soil retained on the construction site, because erosion and sediment control treatments were employed, is computed by:

$$\text{soil retained} = A_2 - A_1 \qquad (3)$$

Therefore, the effectiveness percent of the treatments in retaining soil on the construction site is:

$$\text{\% Effectiveness} = \frac{A_2 - A_1}{A_2} \times 100$$

$$= \frac{RLSK - RLSKCP}{RLSK} \times 100$$

$$= (1 - CP) \times 100 \qquad (4)$$

Equation (4) can now be used to compute effectiveness for the various erosion and sediment control alternatives providing Factor C and P values are assigned for the individual treatment comprising a particular system.

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A. Factor C Values for Urbanizing Areas

Published Factor C values need to be adjusted for urbanizing areas because stabilized surfaces are disturbed by construction traffic. Two assumed construction conditions have been considered:

(1) Construction is completed within 18 months following initial groundbreaking.

(2) When building is started six months after seeding, then construction is completed within 24 months.

It is further assumed that three months of the 18- or the 24-month construction periods are consumed by grading operations, and that construction sites are without surface protection during this time.

Factor C values change with time following surface treatment. For example, Factor C values for grass decrease from 1.0 to about 0.01 between seeding and when the grass is reasonably well established. For construction sites, Factor C values are assumed altered additionally by urban development activities.

A typical example of estimating average Factor C value for seed, fertilizer and straw mulch is as follows, after Reference 26:

Months	Representative Factor C Value	Fraction of Construction Period	Product
0-3*	1.00	3/18	0.167
3-6	0.35	3/18	0.058
6-18	0.19	12/18	0.127

Average Factor C value for 18-month period = 0.352

*During 0-3 months, Factor C value is 1.0 because the construction area has no surface stabilizing treatment.

Table 4 lists the average values of Factor C for various surface stabilizing treatments from Reference 26 and Table 5 lists additional values for more specific ground cover.

TABLE 4

AVERAGE FACTOR C VALUES FOR VARIOUS SURFACE STABILIZING TREATMENTS

(After Reference 26 with some modifications)

Treatment	Factor C Values for Time Elapsed Between Seeding and Building None*	 6 Months**
Seed, fertilizer and straw mulch. Straw disked or treated with asphalt or chemical straw tack.	0.35	0.23
Seed and fertilizer	0.64	0.54
Chemicals (providing 3 months protection)	0.89	--
Seed and fertilizer with chemicals (providing 3 months protection)	0.52	0.38
Chemical (providing 12 months protection)	0.56	--
Seed and fertilizer with chemical (12 months protection)	0.38	--

*Assumes 18 month construction period.
**Assumes 24 month construction period.

Table 5 lists average effectiveness for several types of ground cover presented in Reference 24.

B. Factor P Values For Structures

Structures used in the various control systems are considered as requiring Factor P values to describe their efficiency. These components include small sediment basins, erosion reducing structures, and downstream sediment basins with or without chemical flocculants.

TABLE 5

EFFECTIVENESS OF GROUND COVER ON EROSION LOSS AT CONSTRUCTION SITES

(After Erosion-Siltation Handbook, Reference 24)

Kinds of Ground Cover	Soil Loss Reduction Related to Bare Surfaces (Percent Effectiveness)
*Seedlings	
Permanent Grasses	99
Ryegrass (Perennial)	95
Ryegrass (Annual)	90
Small Grain	95
Millet & Sudangrass	95
Field Bromegrass	97
Grass Sod	99
Hay (2 Tons per Ac)	98
Small Grain Straw (2 Tons per Ac)	98
Corn Residues (4 Tons per Ac)	98
Wood Chips (6 Tons per Ac)	94
**Wood Cellulose Fiber (1-3/4 Tons per Ac)	90
**Fiberglass (1,000 Lbs per Ac)	95
**Asphalt Emulsion (125 Gal per Ac)	98

*Based on full established stand
**Experimental - not fully validated

(1) Small Sediment Basins - The conventional method employs small sediment basins having capacity to inflow ratios of 0.03 to 0.04, with an average trap efficiency of 70 percent. Thus, if the sediment basin collects sediments coming from only 70 percent of the construction area then its Factor P value is (1.00 - 70% x 70%) = 0.50. On the other hand, if it collects sediments from 100 percent of the construction area then its Factor P value is (1.00 - 70% x 100%) = 0.30.

(2) Downstream Sediment Basins - The larger size basin constructed downstream of the construction site and having capacity to inflow ratios of 0.06 to 0.07 will have a trap efficiency of 80 percent, thus, the corresponding Factor P value is 0.20.

Chemical flocculants may be added to this downstream basin to cause more efficient settling of incoming sediment. Such chemicals are assumed to increase the trap efficiency of this basin 90 percent, giving a Factor P value of 0.10.

(3) Erosion-Reducing Structures - Diversion Berms, sodded ditches, interceptor berms, grade stabilization structures and level spreaders are collectively referred to as one system called erosion reducing structures.

The overall effectiveness of erosion reducing structures is estimated at 50 percent. The Factor P value for this normal usage is then 0.50. For higher usage, the erosion reducing structures are estimated to be 60 percent effective, giving a Factor P value of 0.40 for this case.

Factor P values for these systems are summarized in Table 6 and are discussed below.

In using these Factor P values to estimate effectiveness of the erosion and sediment control alternatives, it is assumed that 100 percent of the sediment not caught by the surface stabilization treatments and/or erosion reducing structures is delivered to the sediment basins.

TABLE 6

FACTOR P VALUES FOR COMPONENTS OF EROSION AND SEDIMENT CONTROL SYSTEMS

(After Reference 24 with some modification)

Component	Factor P Value
Small sediment basin: (0.04 ratio)	
Sediment from 70% construction area	0.50
Sediment from 100% construction area	0.30
Downstream sediment basin: (0.06 ratio)	
With chemical flocculants	0.10
Without chemical flocculants	0.20
Erosion reducing structures:	
Normal rate usage (165 ft per ac)	0.50
High rate usage (over 165 ft per ac)	0.40

C. Computing System Effectiveness

The effectiveness of various erosion and sediment control alternatives is computed and listed in Table 7, using the equation:

$$\text{Percent Effectiveness} = (1-CP) \times 100$$

Factors C and P are taken from Tables 4 and 6, respectively.

Factor P values are multiplied if a particular erosion and sediment control alternative has two or more components represented by a Factor P. An example of this calculation is shown using the conventional method of erosion and sediment control.

Conventional Method	Factor C or P Value
Sediment basin (.04)	0.50
Erosion reducing structures (normal)	0.50
Seed, fertilizer and straw mulch	0.35

Percent Effectiveness = $1-(0.35 \times 0.50 \times 0.50) \times 100 = 91.25$ percent.

TABLE 7

PROMISING CONTROL SYSTEM AND EFFECTIVENESS

(After Reference 26 with modifications)

System Numbers	Components	Percent Effectiveness
1	Seed, fertilizer, straw mulch. Erosion structures (normal). Sediment basins (0.04 ratio, and 70 percent of area)	91
2	Same as (1) except chemical (12 months protection) replaces straw	90
3	Same as (1) except chemical straw tack replaces asphalt	91
4	Seed, fertilizer, straw mulch. Diversion berms. Sediment basins (0.04 ratio and 100 percent area)	90
5	Seed, fertilizer, straw mulch. Downstream sediment basin (0.06 ratio)	93
6	Seed, fertilizer, chemical (12 months protection). Downstream sediment basin (0.06 ratio).	92
7	Seed, fertilizer, straw mulch. Downstream sediment basin using flocculants.	96
8	Same as (7) without straw mulch.	94
9	Chemical (12 months protection) sediment basin using flocculants.	94
10	Same as (9) with seed, fertilizer	96

SECTION IX

EVALUATION OF COSTS FOR SELECTED BASINS

1. INTRODUCTION

An initial objective of the present study was to obtain data from at least two climatologically different river basins where development and accompanying, or subsequent, erosion and sediment deposition were occurring. At least one basin was to be selected in the arid west and the other in the more humid eastern United States. The purpose of these different locations was to give a representation of the range of erosion problems and types of erosion control procedures and costs in urban areas as well as costs of correcting erosion and sediment damages in such areas.

In the early stages of data collection it became evident that in order to obtain sufficient data on erosion and sediment control measures, work in several river basins would have to be investigated. This was particularly true for cost data in California. Each of the basins studied contains one or more important specific erosion or sedimentation problem. Consequently, it is felt that the sum total of information collected and analysed presents a representative view of the scope and perspective of urban erosion and sediment problems in California and in the Virginia - Washington, D. C. area.

The two typical river basins selected for more intensive data collection and presentation in this report are: (1) The Occoquan Creek Basin in Virginia, representing the humid region. (2) The Walnut Creek Basin in California, representing the arid region.

In both of these basins considerable residential and commercial development activity is currently taking place.

2. SELECTION CRITERIA

In the basin-selection surveys the following criteria were used both in qualitative and quantitative comparison of the several candidate basins considered in the humid and arid climatic regions.

(1) Numbers of land development, highway, and/or airfield projects, active or recently active, within the basin.
(2) Extent and quality of available data on erosion and sediment damage, control measures and costs.
(3) Availability of processed data by U.S. Soil Conservation Service on rainfall erosion indices, soil erodibility factors and soil surveys.
(4) Availability of rainfall intensity-duration data near the project sites.
(5) Potential extent of construction work in the near future where erosion damage could possibly occur.
(6) Degree to which basin can be considered typical of other basins in the United States.
(7) Distance from basin to project offices and extent of travel required within basin to obtain data.

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Date for the above selection criteria were obtained from the U.S. Department of Commerce's Construction Reports, private banks' reports of building permit activity in the cities and counties of California, and several local, county, state and regional agencies. Other data were gathered from the published literature and open-file records made available by public agencies.

Based on the extent of erosion and sedement problems, several counties were evaluated for the purposes of selecting study areas. Areas with previous intensive records of erosion studies, such as the Seneca Watershed in Maryland, were excluded to avoid duplication. However, existing reports from such areas were obtained and used as a check against data developed herein.

3. RIVER BASINS SELECTED

A. Occoquan Creek Basin, Virginia

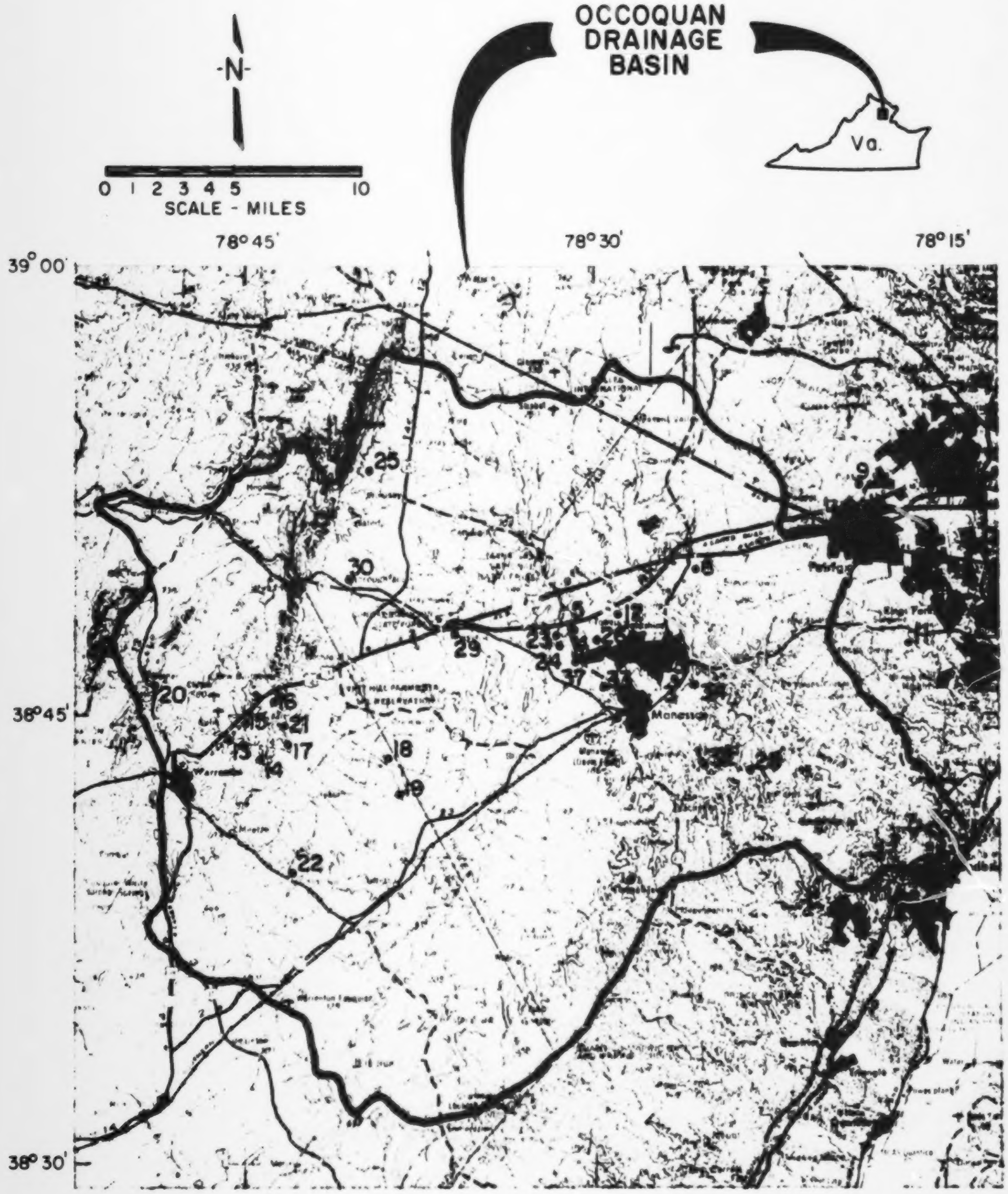
The drainage area of this basin is 546 square miles. The land area comprises portions of four counties in Virginia, namely, Prince William, Fairfax, Loudoun and Fauquier. (Figure 56).

Manassas, Manassas Park and Warrenton are three cities that lie wholly within the boundaries of the basin. Portions of the city of Fairfax and the town of Woodbridge are located inside the basins, but near its periphery.

1. Topography & Soils

The northwestern borders of the Occoquan Basin have rugged terrain. Most of it, however, is moderately undulating land, with the average elevation of this portion being under 250 feet above sea level. Considerable areas of the basin are covered with woods and brushwood.

The most recent and comprehensive soils report for the area was that for Prince William County; data was also available for Fairfax County soils. For the purposes of this study the soils of these two counties were considered sufficiently representative to identify the general nature of soil erosion in the developing portion of the basin. Table 8 lists the predominant soils in Prince William County within the confines of Occoquan Basin, and the estimated K-factor values for both surface soils and subsoils. The method referred to in Section VII, using Figure 52, was used to estimate the soil erodibility K-factors in Prince William County. Percent silt and very fine sand, as well as percent sand were estimated for each soil from the predominant soil type using the soil texture triangle (Figure 57) and by assigning average numerical values representative of each type. Percent organic matter was readily available for some soils. For others, it was estimated from descriptive information on the color, fertility and productivity of soils under consideration. Soil structure and permeability estimates were translated into numerical designations as prescribed by Wischmeier et al. (Reference 137). The variation of soil types found in the areas being developed is usually of importance as it directly affects erodibility variations within the area.


-N-
0 1 2 3 4 5 10
SCALE - MILES
OCCOQUAN DRAINAGE BASIN
Va.
78°45'
78°30'
78°15'
39°00'
38°45'
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25
9
30
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23
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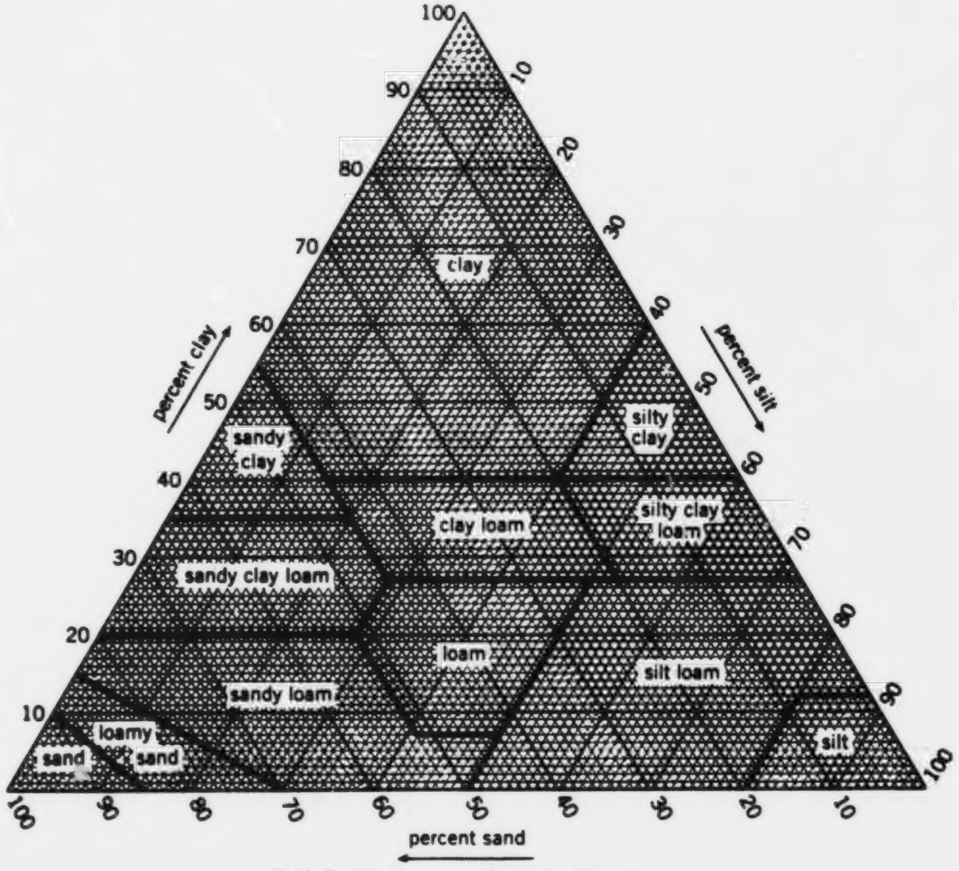
19
22
Manassas

Figure 56. The Occoquan Creek Drainage Basin, Northeastern Virginia (Numbers identify development projects listed in text)


100
90
80
70
60
50
40
30
20
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percent clay
10
20
30
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100
percent silt
100
90
80
70
60
50
40
30
20
10
percent sand
clay
sandy clay
silty clay
clay loam
silty clay loam
sandy clay loam
loam
silt loam
sandy loam
loamy sand
sand
silt

U. S. D. A.

GUIDE FOR TEXTURAL CLASSIFICATION

Soil Separate	Particle Diameter mm
Very Coarse Sand.	.2.00-1.00
Coarse Sand	.1.00-0.50
Medium Sand	.0.50-0.25
Fine Sand	.0.25-0.10
Very Fine Sand.	.0.10-0.05
Silt.	.0.05-0.002
Clay.	.Less Than 0.002

Figure 57. USDA Guide for Textural Classification

TABLE 8

SOIL ERODIBILITY, K, VALUES ESTIMATED FOR SOME SOILS IN PRINCE WILLIAM COUNTY IN THE OCCOQUAN WATERSHED, VIRGINIA

Tentative Map Symbol	Tentative Soil Name	Surface Texture	Estimated K-Factor of Erodibility	
			Surface	Subsoil
11	Bermudian	Silt loam	0.36	- *
14	Manassas	Silt loam	0.44	0.43
16	Beltsville	Loam	0.29	0.13
20	Meadowville	Silt loam	0.44	0.37
29	Ruxton, Cobbly	Silt loam	0.36	-
38	Beltsville	Fine sandy loam	0.37	0.31
40	Mecklenburg	Silt loam	0.38	0.26
48	Iredell	Silt loam	0.43	0.20
52	Elbert	Silt loam	0.37	0.20
60	Appling	Fine sandy loam	0.38	0.16
61	(Loamy and Gravelly Sediments)	-	0.18	0.18
63	Louisburg	Sandy loam	0.08	-
67	Klinesville	Sandy loam	0.07	-
71	Penn and Bucks	Silt loam	0.44	0.31
72	Bucks	Loam	0.22	0.31
73	Penn	Silt loam	0.41	-
75	Penn	Loam	0.21	-
78	Calverton	Silt loam	0.49	-
91	Birdsboro	Silt loam	0.44	0.35
92	Raritan	Silt loam	0.46	0.35
104	Catlett	Silt loam	0.51	-
111	Buncombe	Loamy sand	0.10	-
128	Montalto	Silt loam	0.35	0.19
144	Ruston-Beltsville	Fine sandy loam	0.47	0.49
148	Iredell-Mecklenburg	Silt loams	0.44	0.59
460	Appling-Glenlg	-	0.29	0.31

* The symbol " - " signifies that subsoil is either unweathered parent material or otherwise unamenable to determination of K value.

TABLE 9

VARIATION OF SOILS WITHIN CERTAIN AREAS OF DEVELOPMENT IN THE OCCOQUAN WATER SHED

Name of Development	Predominant Soils Found in the Area
I - PRINCE WILLIAM COUNTY	
Sudley	Bermudian, Manassas, Penn, Bucks, Birdsboro, Raritan
First Virginia Bank Site	Bermudian, Manassas, Penn, Calverton, Catlett
Lewis Tract High School	Bermudian, Meadowville, Ruxton, Mecklenburg, Iredell, Elbert
Connor Tract High School	Manassas, Klinesville, Penn, Calverton
Lake Ridge Development and Woodbridge High School	Beltsville, Appling, Louisburg, Bunchcombe, Appling, Glenelg
Occoquan Dam and Reservoir	Beltsville, Louisburg, Ruxton-Beltsville
Occoquan Area	Beltsville, Loamy and Gravelly Sediments, Ruxton-Beltsville
II - FAIRFAX COUNTY	
K-Mart Shopping Center	Manor, Glenelg
Oakton Shopping Center	Glenville, Rocky Lands, Elioak, Breno, Louisburg
Dansbury Forest	Mixed alluvial lands, Glenville, Meadowville, Manor, Elioak, Fairfax, Glenelg
III - FAUQUIER COUNTY	
Baldwin Ridge	Catoctin, Elioak, Lloyd, Manor, Braddock

TABLE 9 (Continued)

Name of Development	Predominant Soils Found in the Area
III - FAUQUIER COUNTY (Cont.)	
Meadowvale	Manor, Stony hills, Starr, Braddock, Elioak, Thurmont
South Hill	Catoctin, Fauquier, Fauquier-Elioak, Elioak
Mill Run	Manor, Elioak, Fauquier-Elioak, Thurmont, Hazel
Oak Ridge	Fauquier, Catoctin
Marstella	Calverton, Penn, Bucks, Montalto, Wadesboro
White Gate	Wadesboro, Penn, Starr, Calverton, Bucks
Kettle Run	Penn, Calverton, Bucks, Wadesboro
Bethel	Catoctin, Penn, Croton, Stony Hills

Examples of such variation are shown in Table 9 wherein soils occurring in each construction area in the Occoquan watershed are listed by series name. Variations within each series are also present, particularly in surface texture and organic matter content. The values in Table 8 should be considered very preliminary office-type estimates, as complete soil analyses were not readily available.

Table 10 lists erodibility factor, K, and texture for Fairfax County Soils. This table was taken from Fairfax County, Virginia, Erosion-Siltation Control Handbook, August 1972, (Reference 24) and is presented herein for reference purposes.

2. Rainfall and Runoff

The average annual rainfall in Occoquan Basin is approximately 44 in. The distribution of rainfall during a normal year produces maximum erosion index values during the months of May through October. The Occoquan Basin falls within the boundaries of the geographic area listed by Wischmeier and Smith (Reference 136) as number 30. Here, the monthly distribution of rainfall erosion index as a percent of the total annual erosion index is as follows:

	Monthly	Cumulative
May	9 %	9 %
June	15 %	24 %
July	20 %	44 %
August	20 %	64 %
September	10 %	74 %
October	7-1/2%	81-1/2%

The period of high erosion index values coincides with the heavy construction period. Hence, it is very important that erosion and siltation control measures are implemented before, during, and immediately after construction.

The average runoff of Occoquan Creek near Occoquan, Virginia is 490 cfs. From a drainage area of 546 sq mi, this represents 0.90 cfs per sq mi of area.

Recorded extreme discharges are 1.0 cfs and 37,000 cfs for minimum and maximum respectively, the former occurring during December 1941 and the latter occurring during October 1942.

FAIRFAX COUNTY SOILS
TABLE 10 ERODIBILITY FACTORS (K) AND TEXTURES
(after Erosion-Siltation Handbook Reference 24)

Soil Series	Horizon	Normal Texture	Erodibility Class	Class & Range	K Values Norm
Belvoir	B	Silty clay loam	Medium	.24-.32	.28
	C	Silt loam	Medium	.24-.32	.28
Braddock	B	Silty clay loam	Medium	.24-.32	.28
	C	Silty clay loam	Medium	.24-.32	.28
Calverton	B	Silty clay loam	Medium	.24-.32	.28
	C	Silt loam	Medium	.240.32	.28
Chewacla	A	Silt loam w/mica	Low	.10-.20	.17
	C	Silt loam w/mica	Low	.10-.20	.17
Elioak	B	Silty clay loam	Medium	.24-.32	.28
	C	Micaceous silt loam	High	.37-.49	.43
Glenelg	B	Silty clay loam	Medium	.24-.32	.28
	C	Micaceous silt loam Weathered	High	.37-.49	.43
Manor	A	Micaceous loam	High	.37-.49	.43
	C	Weath. Schist	High	.37-.49	.43
Meadowville	B	Silt loam to clay	Medium	.24-.32	.28
	C	Silt loam to clay	Medium	.24-.32	.28
Montalto	B	Silty clay loam	Medium	.24-.32	.28
	C	Course sandy claylm	Medium	.24-.32	.28
Wehadkee	A	Silt loam	Low	.10-.20	.17
	C	Silty clay to lm	Low	.10-.20	.17
Worsham	B	Silty clay loam	High	.37-.49	.43
	C	Silty loam w/rock	Medium	.24-.32	.28

TABLE 11

Developments In and Around Occoquan Drainage Basin, Virginia

1.	Occoquan Reservoir	Prince William Co.
2.	Dale City	"
3.	Lewis Tract High School	"
4.	Conner Tract High School	"
5.	First Virginia National Bank	"
6.	New Gate Development	Fairfax Co.
7.	Lake Ridge Development and Woodbridge High School	Prince William Co.
8.	Woodbridge - Occoquan Area	Prince William Co.
9.	Oakton Shopping Center	Fairfax Co.
10.	K-Mart Shopping Center	"
11.	Dansbury Forest	"
12.	Sudley - 450 acres - 1,611 townhouses & apts	Prince William Co.
13.	Mill Run - 50 acres - 36 lots	Fauquier Co.
14.	Oak Ridge - 30 acres - 25 lots	"
15.	Meadowvale - 150 acres - 51 lots	"
16.	Baldwin Ridge - 100 acres - 42 lots	"
17.	Marstella - 200 acres - 144 lots	"
18.	Whitegate - 24 acres - 12 lots	"
19.	Kettle Run - 125 acres - 57 lots	"
20.	Bethel - 70 acres - 149 lots	"
21.	South Hill - 30 acres - 30 lots	"
22.	Casanova Hills - 145 acres - 19 lots	"
23.	Country Scene - 61 acres - 511 townhouses	Prince William Co.
24.	Coverstone Apartments - 67 acres - 1,000 garden apts	"
25.	Evergreen Farm	"
26.	Irongate - 65 acres - 650 townhouses	"
27.	Lakeridge - 2,974 acres - 8,980 townhouses & apts	"
28.	Occoquan Forest - 978 acres - 2,166 townhouses & apts	"
29.	Lakeview Estates - 94 houses	"
30.	Mountain Farm - 97 houses	"
31.	Point of Woods - 507 houses	"
32.	Hillcrest Estates - 96 houses	"
33.	Ashton Glenn - 45 acres - 528 townhouses & apts	"
34.	Manassas Park Village	"
35.	Elysian Woods - 8 acres - 105 apts	"
36.	Pinewood Forest - 17 acres - 176 townhouses (part of Lakeridge)	"
37.	Crestwood - 14 acres - 100 townhouses	"

3. Development Projects

There

progress and many others still in the planning stage. Table 11, lists the various development in and around the Occoquan Drainage Basin, together with where information was available as to the overall size and type of urban development. The numbers listed refer to the numbers on the basin map.

4. Type and Extent of Control Practiced

In the Occoquan Basin the type and extent of erosion control practiced is in line with standards of the U. S. Soil Conservation Service.

Generally speaking, before construction work is allowed to start, the siltation and erosion control plans for the work must be reviewed and approved by government officials in that area. Thereafter, all erosion and siltation control measures are to be placed prior to or as the first step in grading. Diversion dikes, level spreaders, filter berm and filter inlets, plus a sediment retention basin are the basic components of such erosion control plans. In addition, erosion control structures, temporary and permanent vegetative cover are stipulated or implemented as and where required. Fairfax County has been so "erosion-control" conscious that very recently they put out an Erosion-Siltation Control Handbook (Reference 24).

B. Walnut Creek Basin, California

The drainage area of this basin is 138.4 square miles. It is also known as Pacheco Creek Basin. The basin lies entirely within Contra Costa County in California (Figure 58).

Walnut Creek, Lafayette, Concord, Pleasant Hill, Pacheco, Alamo, Danville and San Ramon are the cities that lie totally or largely within the drainage basin.

1. Topography & Soils

The Soil Conservation Service recently completed the field work of a new soil survey for the Contra Costa County. The results of this survey will be made available sometime in December 1973; however, soil survey maps were made available together with the Contra Costa County General Soil Survey and Report of August 1966 (Reference 19).

Table 12 lists the predominant soils and the estimated K-factor values of these soils in Walnut Creek Basin, for both surface soils and subsoils, and, in certain cases, for parent materials when the soil cover is less than 36 inches in thickness. The method of estimating the K-factor values was as explained for the Occoquan Basin.

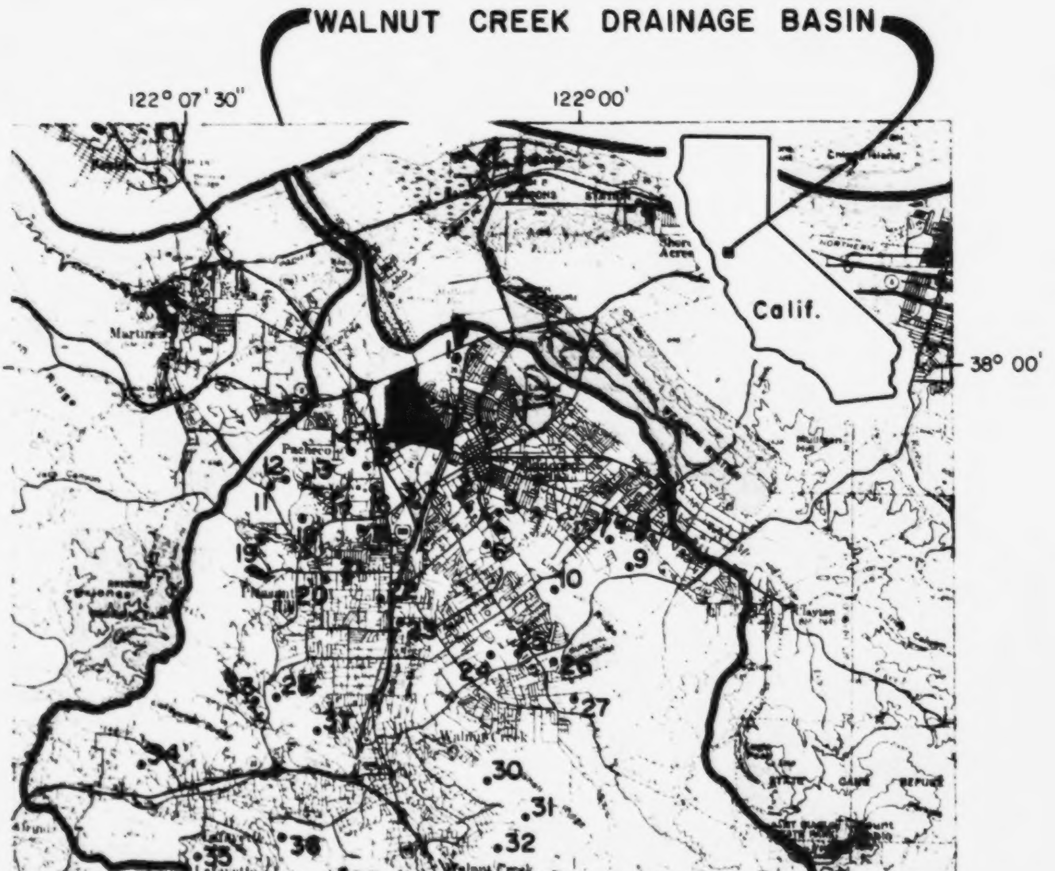
WALNUT CREEK DRAINAGE BASIN
122° 07' 30"
122° 00'
Calif.
38° 00'
37° 45'
Martinez
Pacheco
Walnut Creek
Lafayette
Alamo
Danville
Moraga
San Ramon
1
6
9
10
11
12
13
19
20
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
N
0
1
2
3
4
5
SCALE - MILES

Figure 58. The Walnut Creek Drainage Basin, Central California (Numbers identify development projects listed in text)

TABLE 12

SOIL ERODIBILITY, K, VALUES ESTIMATED FOR SOILS IN CONTRA COSTA COUNTY IN THE WALNUT CREEK WATERSHED CALIFORNIA

Map Symbol	Soil Name	Surface Texture	K Factor		
			Surface	Subsoil	Parent Material*
BN-Zm	Brentwood	Clay loam	0.21	0.33	-
	Zamora	Clay loam	0.23	0.33	-
	Sorrento	Clay loam	0.22	0.35	-
	Los Robles	Clay loam	0.18	0.34	-
BN-Dg	Brentwood	Clay loam	0.23	0.34	-
	Rincon	Clay loam	0.22	0.20	-
	Delhi	Sand	0.03	0.03	-
sy	Sycamore	Silty clay loam	0.31	0.62	-
BN-Rn	Brentwood	Clay loam	0.26	0.37	0.45
	Rincon	Clay loam	0.26	0.18	0.36
CM-Bk	Clear Lake	Clay	0.11	0.18	-
	Botella	Clay loam	0.17	0.40	-
	Salinas	Clay	0.10	0.18	-
Cp-Rn	Cropley	Clay	0.11	0.21	-
	Rincon	Clay loam	0.21	0.13	-
Cp-Rn/B-1	Cropley	Clay	0.10	0.18	-
	Rincon	Clay loam	0.21	0.17	-
Pp	Pescadero	Clay	0.17	0.17	0.19
SX-Sm	Solano	Loam	0.36	0.21	0.33
	San Ysidro	Loam	0.36	0.20	0.31
Sb	Sacramento	Clay	0.13	0.18	0.20

* Parent material erodibility is given for soils with less than 36-inch depth.

TABLE 12 (Continued)

Map Symbol	Soil Name	Surface Texture	K Factor		
			Surface	Subsoil	Parent Material*
Sf-Ed	Staten	Peaty muck	0.01	0.01	-
	Egbert	Mucky clay loam	0.01	0.01	-
pw-Ed	Piper	Sandy loam	0.16	0.24	-
	Egbert	Mucky clay loam	0.11	0.16	-
Dg/Bc-2	Delhi	Sand	0.02	0.02	-
TI-Ax/BD-2	Tierra	Loam	0.30	0.21	0.31
	Antioch	Loam	0.31	0.28	0.31
Pn-Km	Perkins	Clay loam	0.28	0.22	0.15
	Kimball	Clay loam	0.28	0.28	0.29
Dl-An/DE-2	Diablo	Clay	0.11	0.18	-
	Altamont	Clay	0.11	0.18	-
Dl-An/F-2	Diablo	Clay	0.11	0.18	-
	Altamont	Clay	0.11	0.18	-
An-SF/DE-2	Altamont	Clay	0.11	0.18	-
	San Benito	Silty clay loam	0.28	0.41	-
	Linne	Clay loam	0.14	0.32	-
An-SF/F-2	Altamont	Clay	0.11	0.18	-
	San Benito	Silty clay loam	0.28	0.41	-
LE-Ge/FG-2	Los Gatos	Loam	0.28-0.24	0.33	-
	Gaviota	Sandy loam	0.23-0.17	0.22	-
	Sobrante	Clay loam	0.18-0.13	0.32	-
LF-MI-FG-2	Los Osos	Clay loam	0.25-0.21	0.18	-
	Millsholm	Loam	0.27-0.22	0.33	-
	Gazos	Silt loam	0.27-0.22	0.29	-
cv-LF/F-2	Climara	Clay	0.14	0.18	-
	Los Osos	Clay loam	0.25	0.22	-
AE/DE-2	Arnold	Loamy sand	0.12	0.12	-

* Parent material erodibility is given for soils with less than 36-inch depth.

2. Rainfall and Runoff

The average annual rainfall in Walnut Creek Basin is 20 inches. During a normal year 85 percent or more of the total rainfall occurs during the months of November, December, and January. This period of relatively heavy rainfall coincides with the period of minimum construction activity in the area. Therefore, provided that proper protective measures are implemented, very minor erosion problems will be encountered in the basin.

There are no streamflow records available for Pacheco Creek near the mouth, but there are data on discharges for Walnut Creek at Concord. The mean discharge for the period 1965-1970 is 47 cfs from a drainage area of 85.1 square miles or 0.552 cfs per square mile of area (Reference 76).

3. Development Projects

There are over 40 urban development and commercial building projects in progress and many others still in the planning stage. Table 13 lists some of the various developments together with information as to the overall size and type of development.

The numbers listed refer to the numbers on the basin map.

4. Type and Extent of Control Practiced

In the Walnut Creek Basin the problem of erosion is perhaps not as critical as in eastern states. Low values of both the rainfall erosion index and the soil erodibility K-factor are mainly responsible for this. Furthermore, during the period May through September, when construction activities are in full swing, no rainfall of consequence occurs. As a result, the ordinances of Contra Costa County and the various cities within the Walnut Creek basin stipulate only that proper and required erosion control work be implemented by the contractor or builder developer. Nevertheless, some developers expend considerable effort to control erosion, and grading activities are watched by public inspectors to help minimize erosion problems which begin with the fall rains. Contractors are often "caught short" by an early heavy rain, before erosion protection measures are in place, or are effective, resulting in extensive sediment deposits in streets and sewers.

TABLE 13

DEVELOPMENTS IN WALNUT CREEK DRAINAGE BASIN CALIFORNIA

City of Concord

1. Northwood - 30 acres - townhouses & apts
2. Stanwell Industrial Park - 50 acres
3. Concord Industrial Park - 50 acres
4. Spanos - 15 acres - multi-family units
5. San Miguel Apartments - 5 acres
6. Shary Industrial Park - 100 acres
7. Presley Development - 300 acres - single family detached & townhouses
8. Mackay Houses - 20 acres
9. Larwin Co. - 300 acres - single family detached
10. Ygnacio Hills - 50 acres - single family detached houses

City of Pleasant Hill

11. Ridgeview Unit II - 30 acres - single family homes
12. Ridgeview Unit I - 31 acres
13. Golfridge - 12 acres - homes
14. Camel back - 50 acres - townhouses
15. Commercial Developments - 36 acres - stores
16. Briar wood Apartments - 2 acres
17. Valhalla Hills - 12 acres - homes
18. Rexford Homes - 41 acres - townhouses & apts
19. Shannon Hills Unit II - 8 acres - single family
20. Multi-Family - 3 acres
21. Rolling Green - 16 acres - cluster unit housing
22. Spring Meadows + Cleveland - 11 acres - multi-family units
23. Coggins Land - 8 acres - multi-family units

City of Walnut Creek

24. APR District - 17 acres - light industrial development
25. Interland Development - 30 acres - offices
26. Ginnochio - 70 acres - single family homes
27. Carriage Hills - 130 acres - residential
28. Skymont - 300 acres - residential
29. Rossmoor Leisure World - retirement community - 7,000 units yet to build
30. Indian Valley - 305 acres - single family homes
31. Walnut Avenue - Shell Ridge - 200 acres - single family homes
32. Viera-Franco Ranch - 400 acres - townhouses

TABLE 13 (Continued)

City of Lafayette

33. Deutscher - 16 acres - housing, planned unit development
34. Eyring - 30 acres - housing, planned unit development
35. Hamlin - 40 acres - single family homes
36. Subdivision 4381 - 15 acres

Contra Costa County - Unincorporated Area

37. Secluded Valley - 67 acres - residential homes
38. Stone Valley - 50 to 75 acres of scattered single family homes
39. Ackerman Property - 94 acres - single family homes
40. Starview - 45 acres - single family homes
41. Several High Density Townhouse Clusters - 20 to 30 acres, scattered
42. Sycamore Hills - 104 acres - single family homes
43. Danville Station - 169 acres - single family homes
44. Twin Creeks - 300 acres total; building in stages - single and multiple family units

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4. COST OF TYPICAL EROSION AND SEDIMENT CONTROL PLAN

While it had been hoped that costs for actual field examples of erosion control measures could be obtained from developers and contractors in the two selected basins, this was found to be impractical. These costs were rarely identified separately, and the developer/contractor would have had to spend a considerable amount of time and money to provide the information desired. Several were able, however, to supply valuable information on procedures, and the cost of doing some specific part of an erosion control practice, and this information was useful in developing the costs for typical measures set forth elsewhere in this report.

In order to demonstrate the method of application of the unit costs developed in this report, a typical example of a sediment and erosion control plan is presented in Figure 59, from "Guidelines for Erosion and Sediment Control Planning and Implementation," (Reference 120).

The scale was added onto the plan and the quantities were taken off the plan and listed in Table 14. The area of the land is 2.95 ac and the weighted average LS-factor is equal to 1.52.

To calculate the cost of sediment erosion control the appropriate unit cost for each of the erosion and sediment control structures are taken from Section V of this report. The average cost per acre for the project is estimated at $1,340 for California and $1,110 for Virginia. See Table 14 for a summary of the estimate.

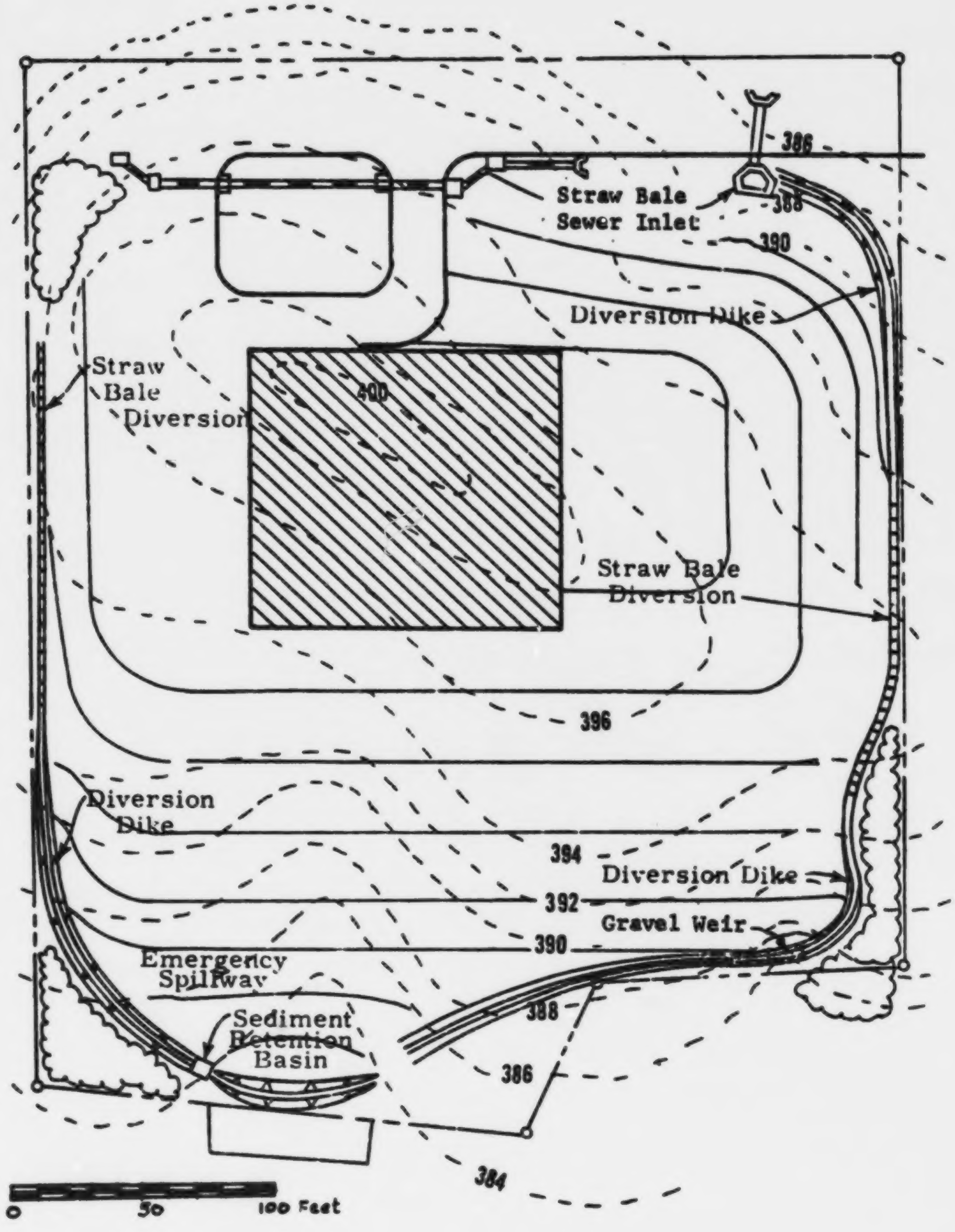
Straw Bale
Sewer Inlet
386
388
390
Diversion Dike
Straw Bale Diversion
400
Straw Bale Diversion
396
Diversion Dike
394
Diversion Dike
392
Gravel Weir
390
Emergency Spillway
Sediment Retention Basin
388
386
384
0
50
100 Feet

Figure 59. Example of Sediment and Erosion Control Plan

TABLE 14

ESTIMATING COST OF SEDIMENT AND EROSION CONTROL PLAN (SEE FIGURE 59)

Item	Unit	Quantity	Unit Cost $	Cost	
				Calif. $	Virginia $
Straw Bale Sewer Inlet	each	1	55.00 (46.34)	55	46
Diversion Dike	L. Ft.	575	4.51 (3.70)	2,593	2,127
Straw Bale Diversion	Bale	90	7.86 (6.62)	707	596
Gravel Weir	6 Ft. ea.	2	10.44 (8.99)	21	18
Sediment Ret. Basin (cost extrapolated)	cu. yd.	36	16.25 (13.75)	585	495
	TOTAL COST For 2.95 acre project			$3,961	$3,282
	Cost per Acre*			$1,340	$1,110
If hydromulch & seeding is used on sloping banks, add for:					
California				$ 720	
Virginia					$ 680
GRAND TOTAL COST PER ACRE				$2,060	$1,790

*Rounded off to nearest ten dollars.

5. ECONOMIC COSTS

The costs that have heretofore been presented are capital or initial, costs. To properly estimate the cost of retaining a unit of sediment on a site, accounting must be made of the amortized cost of this capital investment together with the annual costs of maintaining the protective practice or structure.

Because of the many variables involved, Figure 60 has been prepared to aid in calculating the economic cost of conserving a ton of soil per year. The Figure shows that if $4,000 has been invested initially to conserve 200 tons of soil per year, and it is required to spend another $1,000 per year, perhaps to irrigate as well as to maintain an area protected against erosion, and the life of the practice, before having to be completely redone to be fully effective, is 5 years, the cost of conserving each ton in place is $10 per ton. If only 40 tons per year are saved, then the cost is $50 per ton.

(Special Note applicable to Figure 60: The scale of the graph as shown in this report is not convenient for capital costs under $2,000 and the lower cost vegetative measures such as hydromulching fall in the latter category. A new graph can be drawn, or alternatively, the graph shown can be used by dividing all values shown on the graph by 10, except the value for "Soil Retained in Tons/Year." The dashed line example would then be for an initial cost of $400, an annual maintenance cost of $100/year, and for 200 tons/year retained the annual cost in dollars per ton per year would be $1/ton. Should a different interest rate be considered applicable, only the lines in the lower left quadrant of the Figure need be re-drawn.)

Costs per ton can be converted to cost per cubic yard by application of the proper unit density factor for the particular soil being considered. Table 15 may be used to help in this regard. The values in this table apply to soils in situ prior to erosion. Attention is invited to the fact that care should be exercised in comparing volumes and weights of deposited sediments with those of sediments in situ , to be certain that differences in water content are properly handled.

6. COMPARATIVE COSTS OF CONTROLLING SEDIMENT

A comparative example of the costs of hydromulching to retain soil in place, and the costs of removing eroded and deposited sediment from streets, will be presented for both the Occoquan and Walnut Creek Basins. An area ten acres in size with maximum uninterrupted length of 220 feet in the direction of a uniform 10 percent slope will be used for the comparison.

A. Occoquan Creek Basin

The Occoquan Basin is situated in an area where the value of the annual average erosion index, as given by USDA Handbook No. 282 iso-erodent map

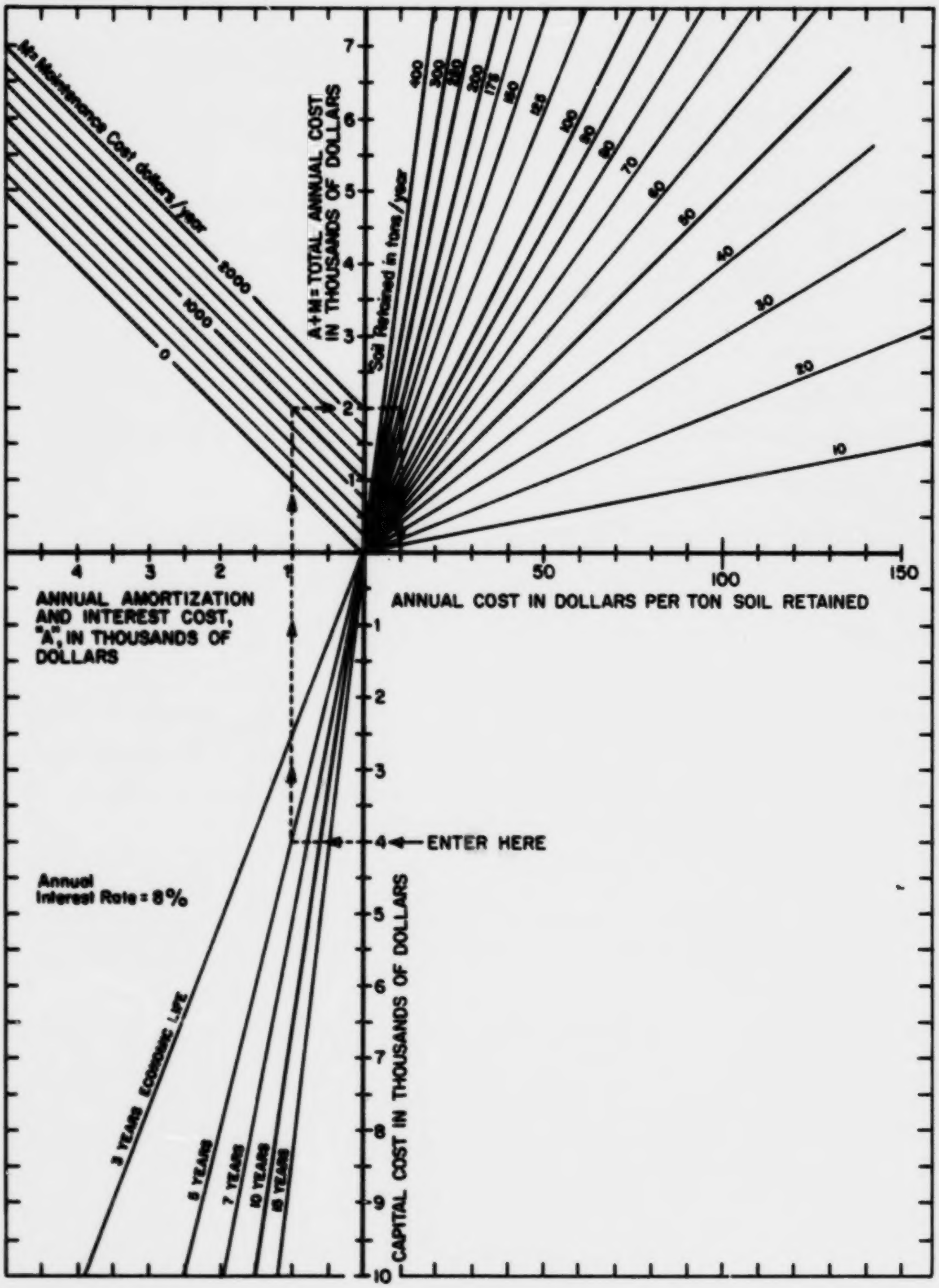

Figure 60. Economic Cost of Conserving a Ton of Soil Per Year

TABLE 15

TYPICAL DRY* SOIL DENSITIES AND EQUIVALENT DEPTHS PER ACRE (IN SITU SOILS UNDER NATURAL CONDITIONS)

	Density		
Soil Type	Lbs/ft^3	Tons/yd^3	Tons/Acre/In
Clay	60-80	0.81-1.08	110-145
Silt	75-85	1.00-1.15	136-154
Clay-silt mixture**	65-85	0.88-1.15	118-154
Sand-silt mixture**	95-110	1.28-1.49	172-200
Clay-silt-sand mixture**	80-100	1.08-1.35	145-182
Sand	85-100	1.15-1.35	154-102
Gravel	85-125	1.15-1.69	154-227
Poorly sorted sand and gravel	95-130	1.28-1.74	172-236

* For moist soils except for highly expandable moist clays use the following formula:

$$D = d + 62.4\ \theta$$

Where: D is density of wet soil, d is the density of dry soil, both in pounds/cubic foot and θ is volumetric moisture content in percent.

**Equal parts

(Reference 136) is nearly 200. For a soil with a K-factor of 0.4, the soil retained by hydromulching is estimated as follows:

$$A = RKLS(1-CP)$$

where $R = 200$
$K = 0.40$ (A typical soil in the basin)
$LS = 2.0$ (From Figure 53)
$(1-CP) = 0.95$ (Combined effectiveness)

$$A = 200\ (0.4)(2.0)(0.95) = 152 \text{ tons per ac per yr}$$

Initial Capital Cost = \$370 per acre (From Table 1)
Annual Maintenance Cost = \$250 per acre (Assumed)

Using Figure 60 with an economic life of 10 years, the following two results are obtained:

Total Annual Cost = \$305 per ac
Cost per ton of Soil Retained = \$2 per ton

B. Walnut Creek Basin

The Walnut Creek Basin is situated in an area where the 2-year 6-hour rainfall is about 1.5 inches. Figure 47 indicates that the average annual erosion index is about 40. Since the soils in the Walnut Creek Basin are generally less-erodible than the soils in the Occoquan Creek Basin, a soil with a K-factor of 0.25 is assumed. Identical plot size and slope and practice effectiveness are assumed. The soil retained by hydromulching is then estimated as follows:

$$A = 40\ (0.25)(2.0)(0.95) = 19 \text{ tons per ac per yr}$$

Initial Capital Cost = \$430 per ac (From Table 1)
Annual Maintenance Cost = \$350 per ac (Assumed higher than in Virginia due to summer irrigation)

Using Figure 60 with an economic life of 10 years, the following two results are obtained:

Total Annual Cost = \$414 per ac
Cost per ton of Soil Retained = \$21.80 per ton

For this particular example the cost per ton of soil retained is more than ten times as much in the Walnut Creek Basin as in the Occoquan Creek Basin. The two principal reasons for this difference are the much greater rainfall erosion potential in Virginia, and the less-erodible soils in the California basin.

Comparison of Costs of Retaining Soil by Hydromulching and Removing Deposited Sediment

10-year Life Project

From the immediately preceding examples and the estimated costs of removing deposited sediments set forth in Section VI, and assuming a soil with an in situ dry weight density of 95 pounds per cubic foot and equivalent volumes for the deposited sediments, the following figures are obtained.

	Virginia	California
Hydromulching Example, Cost of Retaining Soil	$ 2 per ton $ 2.56 per cy	$21.80 per ton $27.90 per cy
Removing Sediment from Streets	$ 6.60 per cy	$ 8.00 per cy
Removing Sediment from Basements	$65 per cy	$77 per cy
Removing Sediment from Sewers	$62 per cy	$68 per cy

C. Projects With Life Less Than 10 Years

While the preceding example for a 10-year life project demonstrates the general economic feasibility to the community of retaining soil in-place, consideration needs to be given also to projects with an economic life less than 10 years.

Using the same general conditions as in the immediately preceding example, the costs of hydromulching projects with shorter economic lives have been estimated, using an interest rate of 8 percent as in Figure 60. Estimates also were made for one-acre areas (where the hydromulching cost is about twice as much per acre as on a 10-acre tract job), and for a one-year life job with no seed or fertilizer and only $100/year/acre maintenance. The latter conditions are considered more realistic than the other one-year estimate, since it would be illogical to spend large sums of money on seed, fertilizer, or maintenance if such a short life were known in advance. Such could be the case for some construction projects. The following costs, and cost ratios, are the result:

Unit Hydromulching Cost per Cubic Yard of Soil Retained - Example

Life of Project	10 yrs	5 yrs	3 yrs	1 yr	1 yr, no seed or fertilizer; $100/acre/year maintenance
Virginia Ratio	1.00	1.12	1.29	2.13	1.44
Cost of Retention					
10-acre area	$ 2.56/cy	$ 2.87/cy	$ 3.30/cy	$ 5.45/cy	$ 3.69/cy
1-acre area *	$ 5.14/cy	$ 5.77/cy	$ 6.63/cy	$10.95/cy	$ 7.41/cy
California Ratio	1.00	1.10	1.25	1.97	1.12
Cost of Retention					
10-acre area	$27.90/cy	$30.70/cy	$34.90/cy	$55.00/cy	$31.25/cy
1-acre area *	$56.00/cy	$61.70/cy	$70.10/cy	$110.50/cy	$62.80/cy

* Based on the assumption that both capital and annual maintenance costs vary proportionately on a per acre basis as the capital costs shown in Figure 1, p. 16.

It may be seen that in the Virginia example the investment in hydromulching is economically justified in most cases on the basis that the costs of retaining the soil in place are less than the direct costs of removing deposited sediment.

On the California area studied, however, the cost of retention is greater than the cost of removing sediments from streets with mechanical loaders and trucks, and protection solely to avoid direct removal costs would not be justified. However, even in California hand removal of sediment from backyards and places where a front-end loader could not have access, is more expensive than the cost of keeping the soil in place. Hence, even in this area of relatively low erosion potential, there are distinct community benefits to be derived from conserving soil-in-place, rather than letting it erode and be deposited elsewhere in an undesired location.

D. Highway Construction (Steep Slopes)

In steeper slopes, the relatively low-cost hydromulching practice is not as effective as the more expensive methods such as excelsior and netting.

The erosion potential on the steep slopes is in turn much greater. For example, on a 2:1 highway slope (equivalent to a 50 percent slope) and assuming an average highway fill slope length of 100 ft, then the topographic factor, LS, estimated from Figure 54, is 12.80. On the other hand, for purposes of comparison the same length of 100 feet in an average development area with a 10 percent slope will have a topographic factor of 1.35 (estimated from Figure 53). In other words, increasing the slope by 5 times means increasing the potential erosion soil-loss by almost 10 times, assuming other factors remain constant. On a 1-1/2:1 highway slope (equivalent to a 66.7 percent slope), the LS for a fill slope length of 100 ft is 19.6. Thus, the potential erosion on highway slopes can be as much as 10 to 15 times those of average development areas. In the Occoquan Creek Basin this means between 2,000 to 3,000 tons per ac per yr, while in the Walnut Creek Basin it means between 400 to 600 tons per ac per yr erosion potential on highway slopes.

Cost per acre for Excelsior Matting is estimated at $10,200 in Virginia and $12,200 in California. Assuming a 95 percent effectiveness and economic life of 5 years, with $250 per ac per yr maintenance required through this period, the estimated costs per ton of soil retained on highway slopes are as follows:

Occoquan

2:1 slope	$1.40 per ton (2,000 tons per yr conserved)
1-1/2:1 slope	$0.93 per ton (3,000 tons per yr conserved)

Walnut Creek

2:1 slope	$8.25 per ton (400 tons per yr conserved)
1-1/2:1 slope	$5.50 per ton (600 tons per yr conserved)

These figures indicate that although excelsior matting requires a high capital input per acre, it can be economically justified for use on steep highway slopes even in the Walnut Creek, California area when steep slopes of 1-1/2:1 or more are encountered.

E. Other Costs and Benefits

It is emphasized again that the costs of sediment removal summarized here are only the direct costs of one aspect of sediment erosion damage. Where erosion damage is so severe as to require repair work, this too is another direct cost, and is not included herein. Furthermore, there are several indirect costs which could be considered, such as interruption of business, inconvenience, etc. However, the objective in this report was to provide a reasonable basis for estimating the most direct costs involved. If these in themselves justify conservation measures, then other costs (benefits) only provide further justification.

It should be stated that the few examples of economic analyses set forth in this report do not cover the entire range of possibilities which can be explored. Each situation really should be studied and judged on its own merits. Rainfall erosion potential, erodibility of the soil, length of time for which protection is needed and difficulty of access are perhaps the more important of the many factors influencing economic costs. If the procedures set forth in this report are followed, using data applicable to the case under study, reliable results can be obtained which can provide a rational basis for actual decisions.

APPENDIX A

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APPENDIX A

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APPENDIX A

DETAILED COST ESTIMATES

Note: All Costs in these tables apply to San Francisco Bay Area, Northern California in late 1972 - early 1973.

I - STRUCTURAL CONTROL MEASURES

Gravel & Earth Check Dam

CONDITIONS OF INSTALLATION:

This is one of the most simple temporary checks to construct. Earth is first dumped in the channel, followed by a layer of gravel on the downstream side of the dumped earth.

PRODUCTION QUANTITIES AND RATES:

a. Costs have been estimated for different sizes of gravel and earth checks:

    (1) 5 ft-wide x 1 ft-high
    (2) 10 ft-wide x 1.5 ft-high
    (3) 15 ft-wide x 2 ft-high

b. Laborers can dig, haul, and compact at a rate of 9 cf/hr. Dozer can spread and compact at a rate of 4 cy/hr.

TABLE A-1

GRAVEL & EARTH CHECK DAM

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATERIAL	LABOR	EQPT
1 ft high, 5 ft wide			
Labor			
Dig, haul & compact earth - 9 cf/hr m-hr 19/9 = 2 m-hr @ $8/hr		16	
Place gravel: $\frac{9}{27}$ cf/ m-hr @ $8.00 x .23 cy		6	
Material			
Gravel @ $10/cy x 0.23 cy	2		
Subtotal	2	22	
45% OH & Profit (small jobs)	1	10	
Total	$3	$32	
Unit Cost — Cost/cf	$.16	$1.68	
$\frac{\$35}{19cf}$ = $1.84/cf			
1.5 ft high, 10 ft wide			
Labor			
85/9 = 9-1/2 m-hr @ $8.00/ m-hr		76	
Place gravel: $\frac{9}{27}$ cf/ m-hr @ $8.00 x .7 cy		18	
Material			
Gravel @ $10/cy x .7 cy	7		
Subtotal	7	94	
45% OH & Profit	3	42	
Total Cost	$10	$136	
Unit Cost — Cost/cf	$.12	$1.60	
$\frac{\$146}{85cf}$ = $1.72/cf			

TABLE A-1 (Cont'd)

GRAVEL & EARTH CHECK DAM

COST ESTIMATES		MATERIAL	LABOR	EQPT
2 ft High, 15 ft Wide				
Labor				
a. 1 Tractor OP 2 hr @ $11.00			22	
b. 1 Laborer 2 hrs @ $8.00			16	
c. Place gravel $\frac{9}{27}$ cf/ m-hr @ $8.00 x 1.4 cy			37	
Material				
Deliver 8 cy earth @ $2.50/cy		20		
Gravel @ $10/cy x 1.4 cy		14		
Equipment				
D4 Dozer 2 hrs @ $10.00				20
	Subtotal	34	75	20
	45% OH & Profit	15	34	9
	Total Cost	$49	$109	$29
Unit Cost $\frac{\$187}{225cf}$ = $.83/cf	Cost/cf	$.22	$.48	$.13

Riprap Check Dam

CONDITIONS OF INSTALLATION:

Excavate by hand, place masonry to grade, and build masonry wall and backfill at same time by hand or with F/E loader.

PRODUCTION QUANTITIES AND RATES:

a. Cost estimates have been prepared for four different size riprap checks:

   (1) 5 ft wide x 2 ft high
   (2) 10 ft wide x 3 ft high
   (3) 15 ft wide x 4 ft high
   (4) 20 ft wide x 5 ft high

b. The following production rates have been used:

   Hand excavation -.0.4 cy/ m-hr
   Masonry - 5.0 cf/ m-hr
   Compacted Fill - 2 cy/hr (machine)
   - 0.3 cy/ m-hr (hand)

TABLE A-2

ROCK RIPRAP CHECK DAM

SAMPLE COST ESTIMATES:

COST ESTIMATE	MATERIAL	LABOR	EQPT
5 ft x 2 ft			
Excav. 5 m-hr @ $8.00		40	
Masonry:			
Deliver Cost = $0.30/cf			
Grout Mat'l = 0.20			
$0.50/cf			
56 x 0.50	28		
Erect 11 m hr @ $10.00		110	
Fill			
7 m-hr @ $8.00		56	
Foreman 4 hrs @ $9.00		36	
Subtotal	28	242	
18% Labor OH		44	
25% OH & Profit	7	71	
Total	$35	$357	
Cost/cf Masonry	$.62	$6.38	

Unit Cost

$\frac{\$392}{56cf}$ = $7.00/cf Masonry

TABLE A-2 (Cont'd)

RIPRAP CHECK DAM

COST ESTIMATE	MATERIAL	LABOR	EQPT
10 ft Wide x 3 ft High			
Excav. 9 m-hr @ $8.00		72	
Masonry:			
Mat'l 131. x 0.50	66		
Erect $\frac{131}{5}$ = 26 m-hr @ $10.00		260	
Fill			
17 m-hr @ $8.00		136	
Foreman - 8 m-hr @ $9.00		72	
Subtotal	66	540	
18% Labor OH		97	
25% OH & Profit	17	159	
Total	$83	$796	
Cost/cf Masonry	$.63	$6.08	
Unit Cost $\frac{\$879}{131cf}$ = $6.71/cf			
15 ft Wide x 4 ft High			
Excav. 10 m-hr @ $8.00		80	
Masonry:			
Mat'l 210 x 0.50	105		
Place 42 m-hr @ $10.00		420	
Fill			
F/E Loader: 7 hrs @ $14.00			98
Loader OP - 8 hrs @ $11.00		88	
Laborer 8 hrs @ $8.00		64	
Foreman - 16 hrs @ $9.00		144	
Subtotal	105	796	98
18% Labor OH		143	
25% OH & Profit	26	235	25
Total	131	1,174	123
Cost/cf Masonry	$.62	$5.59	$.59
Unit Cost $\frac{\$1428}{210cf}$ = $6.80/cf			

TABLE A-2 (Cont'd)

RIPRAP CHECK DAM

COST ESTIMATES	MATERIAL	LABOR	EQPT
30 ft Wide x 5 ft High			
Excav. 13 m-hr @ $8.00/ m-hr		104	
Masonry:			
Mat'l - 300 cf x $0.50/cf	150		
Place: 60 m-hr @ $10.00/ m-hr		600	
Fill			
F/E Loader: 14 hrs @ $14.00			196
Loader OP 16 hrs @ $11.00		176	
Laborer 16 hrs @ $ 8.00		128	
Foreman - 40 hrs @ $9/hr		360	
Subtotal	150	1,368	196
18% Labor OH		246	
25% OH & Profit	38	404	49
Total	188	2,018	245
Cost/cf Masonry	$.63	$6.73	$.82

Unit Cost

$\frac{\$2451}{300cf}$ = $8.17/cf Masonry

Concrete Check Dam

CONDITIONS OF INSTALLATION:

a. The construction procedure is as follows:

(1) Move-in
(2) Excavate for concrete slab
(3) Pour footings and place rebars
(4) Pour concrete
(5) Backfill where necessary
(6) Place timber, misc. steel, and riprap
(7) Clean-up
(8) Move-out

b. Dewatering of site has not been included in cost estimate

PRODUCTION QUANTITIES AND RATES:

a. Cost estimates have been prepared for four different size concrete checks:

(1) 2 ft 4 in high x 5 ft 0 in wide* x 4 ft 0 in long
(2) 5 ft 6 in high x 9 ft 8 in wide x 8 ft 0 in long
(3) 5 ft 0 in high x 17 ft 6 in wide x 14 ft 0 in long
(4) 7 ft 0 in high x 20 ft 0 in wide x 20 ft 0 in long

*Width of stream

TABLE A-3

CONCRETE CHECK DAM

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATERIAL	LABOR	EQPT
No. 1			
Excav. (3.0 cy/hr)			
B/hoe 4 hrs @ $10/hr			40
Operator 5 hrs @ $11.00/hr		55	
Laborer 8 hrs @ $8.00/hr		64	
Concrete			
Forms: 10 Carp. hrs @ $10.00/hr		100	
50 sf @ $0.30/cf	15		
Reinf. 3 m-hr @ $10.00/ m-hr		30	
285 lbs @ $.10/lb	28		
Pour: 6 @ $8.00/ m-hr		48	
2.4 cy @ $20.00/cy	48		
Metalwork			
132 lbs @ ($0.50/$0.30)/lb	66	40	
Timber			
58 bf @ ($0.20/$0.10)/bf*	12	6	
Riprap			
1.5 cy @ ($6.00/$5.00)/cy	9	7	
Mobilization	50	150	50
Subtotals	228	500	90
18% Labor OH		90	
25% OH & Profit	57	148	23
Total	285	738	113
Cost/cy	$150	$388	$59

Unit Cost

$\frac{\$1136}{1.9cy} = \$598/cy$

*bf = board feet

TABLE A-3 (Cont'd)

CONCRETE CHECK DAM

COST ESTIMATE	MATERIAL	LABOR	EQPT
No. 2			
Excav. (6 cy/hr)			
Backhoe 5 hrs @ $10/hr			50
Operator 5 hrs @ $11.00/hr		55	
Laborer 5 hrs @ $8.00/hr		40	
Mobilization	50	150	50
Concrete			
Forms: 27 Carp. hrs. @ $10.00/hr		270	
132 sf @ $.30/sf	40		
Reinf: 16 hrs. @ $10.00/ m-hr		160	
1620 lbs @ $.10/lb	162		
Pour: 40 m-hr @ $8.00/ m-hr		320	
13 cy @ $20.00/cy	260		
Metalwork			
266 lbs @ ($0.50/$0.30)/lb	133	80	
Timber			
187 bf @ ($0.20/$0.10)/bf	37	19	
Riprap			
8.6 cy @ ($6./$5.)/cy	52	43	
Foreman			
24 hrs @ $11.00/hr		264	
Subtotals	$734	$1,401	$100
18% Labor OH		252	
25% OH & Profit	183	413	25
Total	917	2,066	125
Cost/cy	$85	$191	$12

Unit Cost

$\frac{\$3,108}{10.8\text{cy}} = \$288/\text{cy}$

TABLE A-3 (Cont'd)

CONCRETE CHECK DAM

COST ESTIMATE	MATERIAL	LABOR	EQPT
No. 3			
Excav. (8 cy/hr)			
Backhoe 6 hrs @ $10.00/hr			60
Operator 8 hrs @ $11.00/hr		88	
Labor 8 hrs @ $8.00/hr		64	
Concrete			
Forms: 28 Carp. hrs @ $10.00/hr		280	
140 sf @ $.30/sf	42		
Reinf: 27 @ $10.00/ m-hr		270	
2700 lbs @ $.10/lb	270		
Pour: 72 @ $8.00/ m-hr		576	
23 cy @ $20.00/cy	460		
Metalwork			
330 lbs @ ($0.50/$0.30)/lb	165	99	
Timber			
280 bf @ ($0.20/$0.10)/bf	56	28	
Riprap			
13.0 cy @ ($6./$5.)/cy	78	65	
Foreman			
32 hrs @ $11.00/hr		352	
Mobilization	100	200	100
Subtotal	1,171	2,022	160
18% Labor OH		364	
25% OH & Profit	293	597	40
Total	1,464	2,983	200
Cost/cy	$82	$168	$11

Unit Cost

$\frac{4647}{17.8}$ = $ 261 /cy

TABLE A-3 (Cont'd)

CONCRETE CHECK DAM

COST ESTIMATE	MATERIAL	LABOR	EQPT
No. 4			
Excav. (12 cy/hr)			
Backhoe 7 hrs @ $10.00/hr			70
Operator 8 hrs @ $11.00/hr		88	
6 cy Truck 7 hrs @ $12.00/hr			84
Truck Driver 8 hrs @ $9.00/hr		72	
Laborer 8 hrs @ $8.00/hr		64	
Concrete			
Forms: 36 m-hr @ $10.00/hr		360	
172 sf @ $0.30/sf	52		
Reinf: 50 m-hr @ $10.00/ m-hr		500	
4950 lbs @ $0.10/lb	495		
Pour: 125 m-hr @ $8.00/ m-hr		1,000	
41 cy @ $20.00/cy	820		
Metalwork			
435 lbs @ ($0.50/$0.30)/lb	218	130	
Timber			
360 bf @ ($0.20/$0.10)/bf	72	36	
Riprap			
20 cy @ ($6./$5.)/cy	120	100	
Foreman			
32 hrs @ $11.00/hr		352	
Mobilization	150	300	100
Subtotal	1,927	3,002	254
18% Labor OH		540	
25% OH & Profit	482	886	63
Total	2,409	4,428	317
Cost/cy	$73	$134	$10

Unit Cost

$$\frac{\$\,7154}{33.0} = \$\,217/\text{cy}$$

Concrete Chute = 3 ft x 40 ft

CONDITIONS OF INSTALLATION:

a. Trench is excavated with backhoe and trimmed by hand.
b. Before gunite is applied, reinforcing mesh is installed.
c. Edgeforms are not required.

PRODUCTION QUANITITIES AND RATES:

a. Backhoe excavates at a rate of 3 cy/hr or 20 linear ft/hr
b. Trimming ditch required 1 m-hr per 20 sf or 3 linear ft. Mesh is placed at same rate.
c. 3 in. of gunite is applied at a rate of 1 cy/hr.

TABLE A-4

CONCRETE CHUTE

COST ESTIMATE		MATERIAL	LABOR	EQPT
40 ft length				
Excavation:				
Backhoe 14 hrs @ $10/hr				140
Operator 16 hrs @ $11/hr			176	
Laborer 16 hrs @ $8/hr			128	
Trim: Laborer 8 hrs @ $8/hr			64	
Place Mesh: 2 Trimworkers 8 hrs @ $11/hr			88	
Gunite: 240 sf @ $1.50/sf		360		
	Subtotal	360	456	140
	18% Labor OH		82	
	25% OH & Profit	90	135	35
	Total	$450	$673	$175
Unit Costs				
$\frac{\$1298}{40\ \text{lf}} = \$32.45/\text{lf}$	Cost lf	$ 11.25	$ 16.83	$ 4.38
	Cost sf	1.88	2.80	.73
$\frac{\$1298}{240\ \text{sf}} = \$5.40/\text{sf}$				

Diversion Dike

CONDITIONS OF INSTALLATION:

a. No access for trucks - use small tracked front end loader.
b. Compaction by loader trucks and hand rammer.
c. Fill material available within 200 ft of dike.
d. Assume labor is available on job site and no travel time is required for labor.

PRODUCTION QUANTITIES AND RATES:

a. Volume/linear ft. = 0.277 cy + 25% waste and compaction = 0.35 cy/lf.
b. Job size = 15 cy or 15/0.35 = 43 lf dike.
c. Loader can place and compact 15 cy of material in 3 hr + 1 hr travel.
d. 2 laborers shaping and compacting for 3 hr.

TABLE A-5

DIVERSION DIKE

SAMPLE COST ESTIMATES:

COST ESTIMATE	LABOR	EQPT
Equipment Rental		
Loader 4 hrs @ $9.00/hr		36
Rammer 3 hrs @ $2.00/hr		6
Labor		
Loader Op - 4 hrs @ $11.00/hr	44	
2 Laborers - 6 m-hr @ $8.00/hr/ m-hr	48	
SUBTOTAL	92	42
45% OH & Profit (small jobs)	41	19
TOTAL COST	133	61
Cost/lf	$3.09	$1.42

Unit Cost

Cost/lf of Dike = $\frac{194}{43}$ = $4.51/lf

Cost/cy = $\frac{194}{15}$ = $12.93/cy

Erosion Check

CONDITIONS OF INSTALLATION:

a. Manual labor is employed to excavate trench, place mat, and backfill trench.
b. No travel is required for labor.

PRODUCTION QUANTITIES AND RATES:

a. 2 laborers can excavate 1 cy/hr or 6 cy/day (152 lf/day).
b. 2 laborers can place jute mesh and backfill at same rate (152 lf/day).
c. One roll of jute mesh, 48 in. x 225 lf will cover 225 lf of check. Estimate is for 152 lf of jute.

TABLE A-6

EROSION CHECK

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
152 lf			
Furnish Jute			
$45 ÷ 225 lf = $.20/lf			
152 lf x $.20/lf =	30		
Labor			
4 Laborers - 32 m-hr @ $8.00/hr		256	
1 Foreman 8 hrs @ $9.00/hr		72	
SUBTOTAL	30	328	
18% Labor OH		59	
25% OH & Profit	8	97	
TOTAL	38	484	
COST/lf	$.25	$3.18	

Unit Cost

$\frac{\$522}{152\ \text{lf}} = \$3.43/\text{lf}$

Filter Berm

CONDITIONS OF INSTALLATION:

Filter berms are to be placed across construction roads. Gravel shall be delivered to site with one laborer tail-gating and another laborer spreading.

PRODUCTION QUANTITIES AND RATES:

a. Volume = 0.417 cy + 25% wastage
 = 0.520 cy/1f
b. Job size = 30 cy or 30/0.52 = 58 1f
c. Two laborers can tail-gate and spread 30 cy of gravel in 4 hr.

TABLE A-7

FILTER BERM

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR
Labor		
2 Laborers 8 hrs @ $8.00		64
Material		
Deliver 30 cy Gravel @ $5.20/cy	156	
Subtotal	156	64
45% OH & Profit (small jobs)	70	29
Totals	$226	$93
Cost/1f	$3.90	$1.60

Unit Costs

$$\frac{\$319}{58\text{ 1f}} = \$5.50/\text{1f}$$

$$\frac{\$319}{30\text{ cy}} = \$10.63/\text{cy}$$

Flexible Downdrain

CONDITIONS OF INSTALLATION:

Flexible downdrain is attached to existing culvert and staked at 20 ft. intervals on side of slope.

PRODUCTION QUANTITIES AND RATES:

Two laborers work 4 hrs to install 300 ft. of flexible downdrain.

TABLE A-8

FLEXIBLE DOWNDRAIN

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR
Material		
Flexible downdrain		
300 ft of 24-in. dia @ $4.85/ft.	$1455	
Labor		
2 laborers 8 hrs @ $8.00/hr		$64
Subtotal	$1455	$64
45% OH & Profit	655	29
Total	$2110	$93
Cost/lf	$7.03	$.31
Unit Cost		
$\frac{\$2203}{300\text{ lf}} = \$7.34/\text{lf}$		

Flexible Erosion Control Mats

CONDITIONS OF INSTALLATION:

a. Grade stream bed, sew mats together and place on stream bed, and finally inject mortar into mats.
b. Rate of installation can be controlled by the number of concrete pumps used simultaneously.

PRODUCTION QUANTITIES AND RATES:

a. Channel is 25 ft wide and 0.25 mi. long, or 1320 ft x 25 ft = 33,000 sq. ft. Mat is 4 in. thick.
b. Grade with bulldozer @ 250 sq. yd/hr.
Laborer installs mat @ 60 sq. ft/ m-hr

TABLE A-9

FLEXIBLE EROSION CONTROL MATS

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
Material			
1) Flexible fabric form @ $0.38/ft^2 x 33,000 ft^2 =	12,540		
2) Grout - assuming 3/8 in. aggregate ready mix-delivered @ $19/cy with 10% wastage. $.26/ft^2 x 33,000	8,580		
3) Form stakes etc. @ $0.03/ft^2 x 33,000	990		
Labor			
D4 Dozer operator @ $11/hr x (15 hrs work and 1 hr travel)		176	
Installing material $\frac{33{,}000\ ft^2}{60\ ft^2/m/hr}$ = 550 m-hr @ $8.00/hr		4,400	
Pumping mortar $\frac{33000ft^2 x0.333ft/27ft^3/yd^3 x\$64/m/day}{75\ yd^3/5\ m/day}$		1,737	
Cleaning & Misc $\frac{33{,}000\ ft^2}{900\ ft^2/m\text{-}hr}$ x $8/hr		293	
Equipment			
D4 Dozer @ 8 + 2 hr x $16/hr			160
Concrete pump $10/hr @ 70% eff. $0.03/ft^2 x 33,000 ft^2			990
SUBTOTAL	22,110	6,606	1,150
18% labor OH		1,189	
25% OH & Profit	5,530	1,949	290
TOTAL	$27,640	$9,744	$1,440
Cost/sq. ft	$0.84	$0.30	$0.04

Unit Cost

Cost/sq ft = $\frac{\$38{,}824}{\$33{,}000}$ = $1.18

Gabions

CONDITIONS OF INSTALLATION:

a. Access roadway is constructed to stream bed on large jobs.
b. Stream bed is first graded by a dozer.
c. Laborers assemble and wire together gabions.
d. Gabions are filled with 4 in. - 10 in. diameter stone by clamshell or front end loader.
e. Gabions are finally wired shut by laborers

PRODUCTION QUANTITIES AND RATES:

a. Three estimates are prepared for 1-ft deep gabions:

    (1) 10 sq. yd
    (2) 100 sq. yd
    (3) 1000 sq. yd

b. Bulldozer production rate is 250 sy/hr.
c. Gabions are filled by hand at a rate of 0.3 cy/m-hr and by a front end loader at a rate of 10 cy/hr.
d. Gabions are assembled at a rate of 3 sy/m-hr.

TABLE A-10

GABIONS

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
10 sy			
Material			
Gabions 5 @ $7.60	38		
Gravel 4 cy @ $5.75	23		
Labor			
Grade Area - 4 m-hr @ $8.00/hr		32	
Assemble Gabions 3 m-hr @ $8.00/hr 10/3 = 3.33 m-hr		27	
Fill Gabions: $\frac{3.33}{0.3}$ = 11 m-hr @ 8.00/hr		88	
SUBTOTAL	$ 61	$147	
45% OH & Profit	27	66	
TOTALS	$ 88	$213	
Cost/sy	$8.80	$21.30	
Unit Cost			
$301/10 = $30.10/sy			
100 sy			
Road to Site and Grading			
1 Tractor OP 8 hrs @ 11.00/hr		88	
1 Bulldozer D4 9 hr @ $10.00/hr			90
1 Laborer 8 hrs @ $8.00/hr		64	
Material			
Gabions 33 @ $10.60	349		
Gravel 35 cy @ $5.75	201		
Labor			
Assemble Gabions 100 sy/3 sy/m-hr = 33 m-hr @ $8.00/hr		264	
Fill Gabions 3 + 1 = 4 m-hr @ $11.00/hr		44	
Eqpt			
F/E Loader: 4 m-hr @ $14.00/hr			56
SUBTOTAL	$550	$460	$146
18% Labor OH		83	
25% OH & Profit	138	136	36
TOTAL	$688	$679	$182
Cost/sy	$6.88	$6.79	$1.82

TABLE A-10 (Cont'd)

GABIONS

COST ESTIMATE	MATL	LABOR	EQPT
100 sy (cont'd)			
Unit Cost			
$1,549/100 = $15.49 sy			
1000 sy			
Road to Site (see above)		152	90
Material			
Gabions 250 @ $12.80	3200		
Gravel 350 cy @ $5.75	2013		
Labor			
Grading 1000/250 = 4 + 1 hr travel = 5 hrs			
Fill Gabions 333/10 = 33 + 3 hrs travel = 36 hrs			
Assembly 1000/3 + 333 m/hr			
Tractor OP - 5 hrs @ $11.00/hr		55	
Loader OP - 36 hrs @ $11.00/hr		396	
Laborers - 333 m-hr @ $8.00/hr		2664	
1 Foreman - 40 hrs @ $9.00/hr		360	
Eqpt			
D4 Dozer 5 hrs @ $10/hr			50
F/E Loader 36 hrs @ $14/hr			504
SUBTOTAL	$5213	$3627	$644
18% OH		653	
25% OH & Profit	1303	1070	161
TOTAL	$6516	$5350	$805
Cost/sy	$6.51	$5.35	$0.81

Unit Cost

$$\frac{12,671}{1,000} = \$12.67/sy$$

Level Spreader

CONDITIONS OF INSTALLATION:

a. Work done where access by truck is impossible.
b. Excavate with bulldozer and make compacted berms at edge of ditch with excavated material.
c. Travel time required only for equipment.

PRODUCTION QUANTITIES AND RATES:

a. Lengths of level spreader under consideration:

   (1) 15 ft
   (2) 44 ft
   (3) 78 ft

b. D4 Dozer can construct 40 ft of level spreader per hour plus 1 hr travel time.

TABLE A-11

LEVEL SPREADER

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
15 ft Length			
Tractor OP 1½ hrs @ $11.00/hr		16	
Laborer 1 hr @ $8.00/hr		8	
D4 Dozer 1-1/2 hrs @ 8 + 2/hr	___	___	15
SUBTOTAL		$ 24	$ 15
45% OH & Profit		11	7
TOTALS		$ 35	$ 22
Cost/1f		$2.33	$1.47
Unit Cost: 57/15 = $3.80/1f			
44 ft Length			
Tractor OP 2 hrs @ $11.00/hr		22	
Laborer 2 hrs @ $8.00/hr		16	
D4 Dozer 2 hrs @ 8 + 2/hr	___	___	20
SUBTOTAL		$ 38	$ 20
45% OH & Profit		17	9
TOTALS		$ 55	$ 29
Cost/1f		$1.25	$0.66
Unit Cost: 84/44 = 1.91/1f			
78 ft Length			
3 hrs @ $11.00, $8.00, $10.00/hr		33	30
	___	24	___
SUBTOTAL		$ 57	$ 30
45% OH & Profit		26	14
TOTALS		$ 83	$ 44
Cost/1f		$1.06	$0.56
Unit Cost: $\frac{127}{78} = \$1.63/1\text{f}$			

Sandbag Barrier

CONDITIONS OF INSTALLATION:

Sand is dumped at site, and laborers fill sand bags and place them into position.

PRODUCTION QUANTITIES AND RATES:

a. Four laborers fill and place 30 sacks per hr for 6 hr per work day.
b. With 20 percent wastage, quantity of sand required for one day's work is 5.4 tons.

TABLE A-12

SANDBAG BARRIERS

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
Sand - 5.4 tons @ $4.20/ton	$ 23		
Sacks - 180 @ $0.198 each	36		
1 Foreman 8 hrs @ $9.00		$ 72	
4 Laborers 32 hrs @ $8.00		$256	
SUBTOTALS	$ 59	$328	
18% Labor OH		59	
25% OH & Profit	15	97	
TOTAL	$ 74	$484	
Cost/Sandbag	$0.41	$2.69	

Unit Cost

$$\frac{558}{180} = \$3.10/\text{Sack}$$

Sectional Downdrain

CONDITIONS OF INSTALLATION:

a. Excavate with backhoe where accessible, and/or by hand.
b. Grade bed, place pipe, and backfill by hand.
c. A stone bed is placed at lower end of downdrain for erosion protection.

PRODUCTION QUANTITIES AND RATES:

a. Backhoe can excavate 3 cy or 27 lf of ditch, per hr.
b. Hand Labor:

Hand Grading	8 lf/m-hr
Pipe Bedding & Placing Pipe	8 lf/m-hr
Backfill & Tamp	8 lf/m-hr
Overall	2.67 lf/m-hr

c. Cost estimates have been prepared for 40 ft and 234 ft lengths of sectional downdrain with a diameter of 24 in.

TABLE A-13

SECTIONAL DOWNDRAIN

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
40 ft Length - 24 in. Diameter			
Backhoe: 1 hr Travel			
(Case 530) 2 hr Work			
3 hrs @ $10/hr			30
B/hoe Operator: 3 hrs @ $11/hr		33	
24" Pipe 40 1f @ $2.00/1f	80		
Pipe Layer: 1 Foreman, 8 hrs @ $9/hr		72	
2 Laborers, 16 hrs @ $8/hr		128	
Apron:			
Excavation: 4 m/hr @ $8/hr		32	
Furnish Rock: 1 cy @ $6/cy	6		
Place Rock: 4 m/h @ $8/hr		32	
SUBTOTAL	$ 86	$297	$ 30
18% Labor OH		53	
25% OH & Profit	21	87	8
TOTAL	$107	$437	$ 38
Cost/1f	$2.68	$10.93	$0.95
Unit Cost: $\frac{\$582}{40}$ = 14.55/1f			
234 ft Length - 24 in. Diameter			
Backhoe: 9 hrs			
1 hr travel			
10 hrs @ $10/hr			100
Operator: 10 hrs @ $11/hr		110	
Pipe 234 1f: @ $2.04/1f	477		
Pipe Layer:			
1 Foreman 40 hrs @ $9.00/hr		360	
4 Laborers, 88 m/hr @ $8.00/hr		704	
Apron:	6	64	
SUBTOTAL	$483	$1,238	$100
18% Labor OH		223	
25% OH & Profit	121	365	25
TOTAL	$604	$1,826	$125
Cost/1f	$2.58	$7.80	$0.53

Unit Cost:

$\frac{\$2,555}{234\ 1f}$ = $10.91/1f

Sediment Retention Basin

CONDITIONS OF INSTALLATION:

a. Due to possible extreme differences in topography, basin area, and dam configuration, examples of different dam sizes and not basin areas are presented here.

b. The procedure for dam construction includes the following steps:

(1) Strip top 6 in. of soil at dam foundation and in retention basin with dozer and dispose of in trucks. Strip second 6 in. of soil and use for dam construction.
(2) Place spillway pipe and hand backfill around pipe.
(3) Dozer excavates suitable dam material in area and stockpiles it for loading into trucks and haul to dam.
(4) Trucks dump material on dam. Dozer spreads and compacts.

PRODUCTION QUANTITIES AND RATES:

a. Following is a table presenting dimensions and quantities of material used for estimating costs of three different sized dams:

QUANTITIES

Case	Dam Ht and Length	Cubic Yard Stripping (cy)	Length and Size Spillway Pipe	Dam Fill (cy)	Cubic Yard Riprap (cy)
A	6'H x 30'L	266	40'-6" , 5'-12"	133	3
B	7'H x 30'L	340	44'-12" , 6'-18"	170	3
C	8'H x 40'L	570	48'-12" , 7'-18"	285	3

b. The following list shows the production rates involved in constructing the dams:

D4 Dozer Stripping	100 cy/hr
1-1/4 CY F/E Loader:	36 cy/hr
D4 Dozer Spread & Compact:	30 cy/hr
Place Spillway Pipe:	5 lf/m-hr
Hand Backfill:	6 lf/m-hr

TABLE A-14

SEDIMENT RETENTION BASIN

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
A. 6 ft x 30 ft			
Stripping & Stockpiling			
1 D4 Tractor 4 hrs @ $10.00/hr			40
Tractor Operator 4 hrs @ $11.00/hr		44	
922 Loader 4 hrs @ $14.00/hr			56
2, 6 cy Trucks 8 hrs @ $12.00/hr			96
Loader Operator 4 hrs @ $11.00/hr		44	
2 Truck Drivers 8 hrs @ $9.00/hr		72	
Place & Backfill Pipe			
Labor: 9 m-hr place 8 m-hr Backfill 17 m-hr @ $8.00/hr		136	
Pipe: 40 lf @ $1.45 lf + 5 lf @ 3.85/lf	77		
Seepage barriers lump sum	10		
Fill & Riprap			
D4 Tractor 6 hrs @ $10.00/hr			60
Tractor Operator 6 hrs @ $11.00/hr		66	
Loader 5 hrs @ $14.00/hr			70
Loader Operator 5 hrs @ $11.00/hr		55	
2, 6 cy Trucks 10 hrs @ $12.00/hr			120
2 Truck Drivers 10 hrs @ $9.00/hr		90	
3 Laborers, 24 hrs @ $8.00/hr		192	
1 Foreman, 8 hrs @ $10.00/hr		80	
Riprap 3 cy @ $6.00/cy	18		
SUBTOTAL	$105	$779	$442
18% Labor OH		140	
25% OH & Profit	26	230	111
TOTAL	$131	$1,149	$553
Cost/cy	$0.98	$8.64	$4.16

Unit Cost

$\frac{1,833}{133}$ = $13.78/cy

TABLE A-14 (Cont'd)

SEDIMENT RETENTION BASIN

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
B. 7 ft x 30 ft			
Stripping & Stockpiling			
Same as Above + 25%		200	240
Place & Backfill Pipe			
Labor: 10 m-hr Place			
8 m-hr Backfill			
18 m-hr @ $8.00/hr		144	
Pipe: 44 lf @ $3.17/lf +			
6 lf @ 5.60 lf	177		
Seepage Barriers			
Lump Sum	10		
Fill and Riprap			
D4 Dozer 6 hrs @ $10.00/hr			60
1 Dozer Operator 6 hrs @ $11.00/hr		66	
F/E Loader 5 hrs @ $14/hr			70
1 Loader Operator 5 hrs @ $11.00/hr		55	
2, 6 cy Trucks 10 hrs @ $12.00/hr			120
2 Truck Drivers 10 hrs @ $9.00/hr		90	
3 Laborers 30 hrs @ $8.00/hr		240	
1 Foreman 10 hrs @ $10.00/hr		100	
Riprap 3 cy @ $6.00/cy	18		
SUBTOTAL	$205	$ 895	$490
18% Labor OH		161	
25% OH & Profit	51	264	123
TOTAL	$256	$1,320	$613
Cost/cy	$1.51	$7.76	$3.61

Unit Cost

$\frac{2,189}{170} = \$12.88/cy$

TABLE A-14 (Cont'd)

SEDIMENT RETENTION BASIN

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
C. 8 ft x 40 ft			
Stripping & Stockpiling			
(Same as A Above + 100%)		320	384
C. 8 ft x 40 ft (Cont'd)			
Place & Backfill Pipe			
Labor: 11 m-hr Place			
8 m-hr Backfill			
19 m-hr @ $8.00/hr		152	
Pipe: 48 @ $3.27 lf + 7 @ $5.60/lf	196		
Seepage Barriers	10		
Fill and Riprap			
1 D4 Dozer 10 hrs @ $10.00/hr			100
1 Dozer Operator 10 hrs @ $11.00/hr		110	
1 P/E Loader 8 hrs @ $14.00/hr			112
1 Loader Operator 8 hrs @ $11.00/hr		88	
2, 6 CY Trucks 16 hrs @ $12.00/hr			192
2 Truck Drivers 16 hrs @ $9.00/hr		144	
3 Laborers 30 hrs @ $8.00/hr		240	
1 Foreman 12 hrs @ $10.00/hr		120	
Riprap 3 cy @ $6.00	18		
SUBTOTAL	$224	$1,174	$788
18% Labor OH		211	
25% OH & Profit	56	346	197
TOTAL	$280	$1,731	$985
Cost/cy	$0.98	$6.08	$3.45

Unit Cost

$$\frac{2996}{285} = \$10.51/\text{cy}$$

Straw Bales

Storm Sewer Inlet Protection

CONDITIONS OF INSTALLATION:

Site surrounding inlet is graded and then straw bales are placed around inlet and staked by laborers.

PRODUCTION QUANTITIES AND RATES:

a. Seven bales of straw are used per inlet; however, the number of bales used will vary with the inlet configuration.
b. A 2-man crew can place and stake one bale in 10 min., or 3 bales per m-hr per 7-hr work day.

TABLE A-15

STRAW BALE INLET PROTECTION

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
Straw			None
Cost $30/ton			
20 bales/ton 1.50/ea			
Stakes 2 @ .25 .50			
2.00			
For 3 Inlets (21 Bales)			
21 Bales @ $2.00/bale in place	42		
$\frac{21}{3} = 7 + 2$ (travel) = 9 m-hr			
@ $8.00 =		72	
SUBTOTAL	$ 42	$ 72	
45% OH & Profit	19	32	
TOTAL COST	$ 61	$104	
Cost/Bale	$2.90	$4.96	

Unit Cost

Per Bale: $\frac{165}{21} = \$7.86$

Per Inlet: $\frac{165}{3} = \$55$

Straw Bale Barriers

CONDITIONS OF INSTALLATION:

Similar to that for storm sewer inlet protection; however, a gravel wier must also be installed.

PRODUCTION QUANTITIES AND RATES:

Production quantities and rates are the same as for storm sewer inlet protection.

TABLE A-16

STRAW BALE BARRIERS

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
Unit Cost Per Bale From Inlet Protection = $7.86			
For each barrier there will be a gravel weir, 6 ft x 4 ft x 8 in. = 16 cf			
Per Barrier $\frac{16\ \text{cf}}{27} \times \frac{2700}{2000} = 0.8$ tons			
0.8 x $4.00/ton	3.20		
Shaping Weir: 0.5 m-hr	____	4.00	
SUBTOTAL	$3.20	$4.00	
45% OH & Profit	1.44	1.80	
TOTAL per weir	$4.64	$5.80	
Unit Cost 10.44/Weir + (No. of Bales) x $7.86			

II - PROTECTION OF GROUND SURFACE

TABLE A-17

EXCELSIOR MAT

One-Acre Plot	California		
	MATL	LABOR	EQPT
1. Excelsior rolls (3 ft x 150 ft) $\frac{43,560}{3 \times 150}$ x $16.00/roll	1,550		
2. Fertilizer	24		
3. Seed	52		
4. Light application of Fibermulch	112		
5. Hydroseeder labor		220	
6. Excelsior labor 96.8 rolls x 8 hr x $8.00		6,195	
7. Transportation			50
8. Equipment			120
9. Move-in & Move-out		128	120
SUBTOTAL	$1,738	$6,543	$290
18% labor OH		1,178	
25% OH & Profit	435	1,930	72
Cost/ac	$2,173	$9,651	$362
Overall Cost/ac		$12,186	
Round off to		$12,200/acre	

TABLE A-18

JUTE MESH, ONE-ACRE PLOT

(Steep Slope)
(Ludlow Soil Saver)
(4' x 225' roll)

California

		MATL	LABOR	EQPT
1.	Ludlow Soil Saver with 6-in. overlap on all edges gives 787 sq ft/roll $\frac{43,560}{787} \times \$30/\text{roll}$	1,660		
2.	Staples 225/roll $\frac{43,560}{787} \times 225 \times \$15/1000\ \text{staples}$	187		
3.	Fertilizer $\frac{15\ \text{lb}}{1000\ \text{sq ft}} \times$ $\frac{43,560}{2,000} \times \$72/\text{ton} =$	24		
4.	Seed 200 lb/acre $\times \frac{\$26}{100\ \text{lb}}$	52		
5.	Fiber Mulch	113		
6.	Hydroseeder & mesh labor			
	2 men x 4 hrs x $8		64	
	($43,560 ÷ 787) 6 hr/roll x $8		2,657	
7.	Transportation			50
8.	Rental 4 hrs @ $30/hr			120
9.	Move-in & Move-out			
	$\frac{1}{2}$ x 2 x 8 x $8		64	
	2 x 8 x $8		128	
	$\frac{1}{2}$ x 8 x $30			120
10.	Labor Supervision		340	
SU	SUBTOTAL	$2,036	$3,253	$290
	18% Labor OH		585	
	25% OH & Profit	509	960	73
	Cost/acre	$2,545	$4,798	$363
	Overall Cost/acre		$7,706	
	Round off to		$7,700/acre	

TABLE A-19

STRAW OR HAY

10-acre plot	California		
	MATL	LABOR	EQPT
1. Straw @ 4 tons/acre applied in two layers with each layer incorporated into soil by a modified sheepfoot roller (cultipacker). 4 tons/ac x 10 ac x $30/ton	1,200		
2. Seed and fertilizer			
3. Labor 4 tons/man day 8 (40 tons ÷ 4) $10		800	
4. Labor for punching straw with cultipacker 8 (10 acres + 2½ ac/man day) x $10 done twice		640	
5. Rentals Cultipacker - 8 days x 8 hr x $25/hr			1,600
Blower - 10 days x 8 hr x $25/hr			2,000
6. Transport			200
7. Move-in & move-out (2 x 4 x 8 x $10)		640	
(2 x 8 x $25) 2			800
8. Labor Supervision		245	
SUBTOTAL	$1,960	$2,325	$4,600
18% Labor OH		418	
25% OH & Profit	490	686	1,150
Cost/Ac	245	343	575
Overall Cost/Ac		$1,163	
Round off to		$1,200/acre	

TABLE A-20

WOODCHIPS

3-in Cover Over One Acre California

	MATL	LABOR	EQPT
1. Wood chip $43,560 \times \frac{3}{12} \times \frac{1 \text{ cy}}{27 \text{ cf}} \times \$4.00/\text{cy}$	1,612		
2. Labor for spreading $(43,560 \times \frac{1}{4} \times \frac{1}{27}) \rightarrow 2$ cy/m/hr x $8.00 =		1,612	
3. Rental 5 days 8 x 2 trucks @ (9.63 + 9.00) =			1,490
4. Move-in & Move-out			
2 (5 men x 8) x $8		640	
2 x 8 x 2 x 9.63			380
5. Labor supervision		265	
SUBTOTAL	$1,612	$2,517	$1,798
18% Labor OH		453	
25% OH & Profit	403	743	450
Cost/Ac	$2,015	$3,713	$2,248
Overall Cost/ac		$7,976	
Round off to		$8,000/acre	

TABLE A-20 (Cont'd)

WOODCHIPS

3/4 in. Cover with Seed and Fertilizer — California
One Acre in California

	MATL	LABOR	EQPT
1. Woodchips: $43{,}560 \times \frac{3/4 \text{ in.}}{12} \times \frac{1 \text{ cy}}{27 \text{ cf}} \times \$4/\text{cy}$	402		
2. Fertilizer: $\frac{15 \text{ lb}}{1000 \text{ sq ft}} \times \frac{43{,}560}{2{,}000} \times \$72/\text{ton}$	24		
3. Seed: $200 \text{ lb/ac} \times \frac{\$26}{100 \text{ lb}}$	52		
4. Labor:			
Hydroseeder 2 x 4 x $8		64	
Chip spreading $8 $(43{,}560 \times \frac{3/4}{12} \times \frac{1}{27}) \div 2$		402	
5. Rentals:			
1½ days x 8 x 2 trucks @ (9.63 + $9.00)			447
4 hrs x $30 for hydroseeder			120
6. Transportation			50
7. Move-in and Move-out:			
½ day x 2 men x 8 hr x $8		64	
1 x 5 x 8 x $8		320	
2 x 1 x 8 x $9.63			154
½ x 8 x $30			120
8. Labor Supervision		100	
SUBTOTAL	$478	$ 950	$891
18% Labor OH		171	
25% OH and Profit	120	280	223
Cost Per Ac	$598	$1,401	$1,114
Overall Cost Per Acr		$3,113	
Round off to		$3,100/acre	

TABLE A-21

4-in. SQUARE PLUGS OF SOD @ 12 in. c/c

One Acre Plot	California		
	MATL	LABOR	EQPT
1. 4-in square plugs of sod set @ 12 in. c/c both directions			
$\frac{43{,}560 \text{ sq ft}}{1 \text{ plug sq ft}}$ x 1½¢/plug	653		
2. Fertilizer	24		
3. Precultivation & Soil preparation complete @ 4¢/sq ft			1,743
4. Labor for setting			
(43,560 ÷ 120 sq ft/m/hr) $8		2,904	
5. Establishment expenses Water applied by portable sprinkler system @ $750/ac/month x 3 mos			2,250
6. Move-in & Move-out		128	400
7. Labor Supervision		354	
SUBTOTAL	$677	$3,386	$4,393
18% Labor OH		609	
25% OH & Profit	170	999	1,098
Cost Per Acre	$847	$4,994	$5,491
Overall Cost/Ac		$11,332	
Round off to		$11,300/acre	

TABLE A-22

SODDING

Hybrid Bermuda Grass Blanket Sodding
One-Acre Plot

California

	MATL	LABOR	EQPT
1. Hybrid Bermuda Grass 16 in. wide strips 43,560 sq ft @ 12¢/sq ft delivered	5,227		
2. Fertilizer	24		
3. Labor for laying sod (43,560 sq ft ÷ 250 sq ft/m/hr) x $8		1,394	
(allow 400 sq ft/m/hr) (for level or flat slope land)			
4. Precultivation & soil preparation complete @ 4¢/sq ft 43,560 x 4¢ (range 3 to 5¢/sq ft)			1,742
5. Establishment expenses Water applied by watertruck @ $800/ac/month x 3 months			2,400
6. Move-in and Move-out		128	400
7. Labor Supervision		178	
SUBTOTAL	$5,251	$1,700	$4,542
Labor		306	
25% OH & Profit	1,313	502	1,136
Cost/Ac	$6,564	$2,508	678
Overall Cost/Ac		$14,750	
Round off to		$14,800/ acre	

TABLE A-23

CHEMICAL SOIL STABILIZER - PETROSET SB
STANDARD OPERATION - NO FUMIGATION

10 Acres California

	Material	Labor	Equip't
1) Petroset SB. Rainwater Erosion protection on Intermediate Grain soils; 1:7 Dilution Ration of SB: Water; 1/2" penetration depth: Dilution Application Rate of Diluted Solution = 0.5 gal/sq yd 3025 gals of SB @ $2.50/gal.	$7,563		
2) Fertilizer (same as for Wood Fiber Mulch)	235		
3) Seed (same as for Wood Fiber Mulch)	520		
4) Hydroseeder labor, for sloping ground, application rate = 0.5 ac/hr/2-man crew, total time - 20 hrs. 2 x 16 hr x $10 + 2 x 4 hr x $15 (overtime rate)		440	
5) Transport: Hydroseeder, 2 hr x $25			50
6) Rentals: Hydroseeder 20 hrs x $30			600
7) Move-in & Move-out 2 x 2 x 8 x $10 2 x 8 x $30		320	
8) Labor supervision		90	480
Subtotals	$8,318	$850	$1,130
18% for Labor Overhead		153	
25% for Overhead & Profit	2,079	251	283
Grand Total	$10,397	$1,254	$1,413
Cost Per Acre	$1,040	$ 125	$ 141
Overall Cost per Acre		$1,306	
Round off to	$1,300/acre		

III - REMOVAL OF SEDIMENT

From Streets and Basements

PRIMARY USAGE:

Removal of sediment from streets and basements is employed in areas where surface runoff has left deposits of sediment in these areas.

DESCRIPTION:

Sediment accumulation on streets and in basements can render both of these areas unusable.

For sediment removal from streets, a front-end loader and a dump truck can be employed to deposit the sediment in an acceptable location. For sediment removal from basements, hand labor can remove the sediment from the basement, at which point a dump truck can transport it to the disposal area.

From Streets

CONDITIONS OF REMOVAL:

A front-end loader scrapes sediment from street and loads the material into 6 cy dump truck for ultimate disposal. A broom is used for final cleaning of street.

PRODUCTION QUANTITIES AND RATES:

A front-end loader operates at a rate of 18 cy/hr or 3 truck loads per hour. In 6 hours, 108 cy can be removed, or 648 sq. yd. with a depth of 6 in.

TABLE A-24

SEDIMENT REMOVAL FROM STREETS

SAMPLE COST ESTIMATE:

COST ESTIMATE	LABOR	EQPT
Eqpt Rental		
1, F.E Loader (Cat 922) - 8 hrs. @ $11.50/hr		92
2, 6 cy Trucks - 16 hrs. @ $10.25/hr		164
Labor		
1 Foreman - 8 hrs.@ $9.00	72	
1 Loader Op - 8 hrs. @ $11.00	88	
2 Truck Drivers - 16 hrs @ $9.00	144	
1 Laborer - 8 hrs. @ $8.00	64	
Subtotal	368	256
18% Labor OH	66	
25% OH & Profit	109	64
Total	$543	$320
Cost/cy	$5.03	$2.96

Production

6 hrs @ 18 cy/hr = 108 cy

@ 6" depth = 648 sq. yd

$\frac{\$863}{108} = \$7.99$ /cy

@ 6" Depth

$\frac{\$863}{648} = \$1.33$/sq. yd

From Basements

CONDITIONS OF REMOVAL:

Laborers first load basement sediment into wheel barrows, then material is dumped onto a conveyor for removal from the basement. Once outside the building, sediment is loaded by a front-end loader into a dump truck for disposal.

PRODUCTION QUANTITIES AND RATES:

a. Production rate is limited by rate at which laborers work. Two laborers can each load 6 wheel barrow loads per hour for 6 hrs per day or 36 wheel barrows @ 3cf = 4cy/day (with one laborer operating wheel barrow)
b. The example is for one day's work with 3 laborers plus one foreman.

TABLE A-25

SEDIMENT REMOVAL FROM BASEMENTS

SAMPLE COST ESTIMATE:

COST ESTIMATE (PER DAY)	LABOR	EQPT
Labor		
3 Laborers - 24 m/hr @ $8.00/hr	192	
1 Truck Driver 3 hrs @ $9.00/hr	27	
1 Loader Op 3 hrs @ $11.00/hr	33	
1 Foreman 8 hrs @ $9.00/hr	72	
Eqpt		
1 Conveyor 8 hrs @ $4/hr =		32
1 F/E Loader 3 hrs @ $14/hr		42
1 6 cy Truck 3 hrs @ $12/hr		36
Subtotal	324	110
18% Labor OH	58	
25% OH & Profit	96	28
Total	478	138
Cost/cy	$59.75	$17.25

Unit Cost

$\frac{\$616}{8} = \$77/cy$

@ 6" Depth - $\frac{77.00}{6 \times 9} = \$1.43/sq.ft$

From Storm Sewers

PRIMARY USAGE:

This practice is used in areas where storm sewers collect surface runoff from construction sites and sediment carried by the runoff can eventually clog the sewer. Two methods of storm sewer cleaning, bucket line cleaning and rodding with vacuuming, are presented in this study.

DESCRIPTION:

Using a bucket line is a method by which buckets are pulled by a line between two manholes in the sewer, thus removing the debris from one manhole. A bucket line normally requires four laborers.

The second method of cleaning entails rodding and cleaning with a unit such as the Vactor®. The Vactor® is a truck mounted unit which combines both the features of rodding and vacuuming. These two processes operate simultaneously using one manhole. Rodding is the spraying of water at a high velocity through a special nozzle, in the storm sewer. As the rodder moves through the sewer, the sediment is flushed back towards the manhole, at which point the vacuum removes the water and sediment from the manhole and stores it in the truck. This operation requires the Vactor®, one operator, and one laborer.

Bucket Line Cleaning

CONDITIONS OF INSTALLATION:

Four laborers operate the bucket line, loading the material into a dump truck.

PRODUCTION QUANTITIES AND RATES:

A storm sewer, 300 ft long with 24 in diameter, is approximately one half full with from 2-1/2 to 3 in rocky shale and gravel. The total quantity of material to be removed is 17.5 cy. The task requires 4 laborers, 4 days.

TABLE A-26

BUCKET LINE CLEANING

SAMPLE COST ESTIMATE:

COST ESTIMATE	MATL	LABOR	EQPT
Equipment			
One 6 cy dump truck @ $7/hr x 32 hrs			224
One dray bucket @ $60/day x 4 days			240
Labor			
4 laborers @ $8/hr x 32 hrs ea.		1024	
1 truck driver @ $9/hr x 32 hrs		288	
Subtotal		$1312	$464
18% labor OH		$ 236	
25% OH & Profit		$ 387	$116
Total		$1935	$580
Unit Cost			
$\frac{\$2515}{17.5\text{ cy}}$ = $144/cy		$ 111	$ 33

Rodding and Hydraulic Flushing of Storm Sewer

CONDITIONS FO INSTALLATION:

One laborer and operator are required for using a Vactor^{R} to rod and hydro-flush the storm sewer. Periodically the Vactor^{R} must be refilled and its sediment load dumped.

PRODUCTION QUANTITIES AND RATES:

The task consists of cleaning a storm sewer, 24 in. diameter by 250 ft long, which is 28 percent filled with debris. Material to be removed consists of rocky shale and gravel, of approximately 2-1/2 to 3 in.size. Eight cubic yards of material must be removed, the job requires a one-day use of the Vactor^{R}.

TABLE A-27

RODDING & HYDRAULIC FLUSHING FROM STORM SEWER

SAMPLE COST ESTIMATE:

COST ESTIMATE		EQPT	LABOR
Equipment			
Vactor 800* @ $240/day		$240	
Fuel		14	
Labor			
Vactor operator @ $11/hr x 8			88
Laborer @ $8/hr x 8			64
	Subtotal	$254	$152
	18% Labor OH		$ 27
	25% Office OH & Profit	$ 63	$ 45
	Total	$317	$224
Unit Cost $\frac{\$541}{8}$ = $68/cy		$ 40	$ 28

* Unit is leased and travel distance less than 100 miles

APPENDIX B

PART 1 - HYDROLOGIC ASPECTS OF THE UNIVERSAL SOIL LOSS EQUATION

1. THE ARS "UNIVERSAL SOIL LOSS EQUATION"

The universal soil loss equation developed by the Agricultural Research Service is a semi-empirical predictive relationship between the mass of soil loss per unit area and all major factors known to influence rainfall erosion. It has the form:

$$A = RKLSCP \tag{1}$$

where: A = the computed soil loss in tons per ac from a given storm period,
R = the rainfall erosion index for the given storm period in units of ft-ton in. per ac-hr (described further below),
and K, L, S, C, and P are other important factors which were defined and discussed briefly in Section VII of this Report.

This appendix sets forth the reasoning and mathematics of the determination of R, the rainfall erosion index, from basic hydrologic data.

The rainfall factor, R, is the rainfall erosion index reported by Wischmeier (Reference 135) and defined for a single storm as:

$$R = \frac{EI}{100} \tag{2}$$

where, E = the total kinetic energy of a given storm in ft-tons per ac and I is the maximum 30-min rainfall intensity for the area in in. per hr.

The rainfall factor is thus a composite term, representing the effects of raindrop impact for the entire storm duration and maximum rainfall intensity. The kinetic energy of rainfall has been given by Wischmeier and Smith (Reference 135) as:

$$E = 916 + 331 \log_{10} I \tag{3}$$

where, I is rainfall intensity (in. per hr). It is thus evident that the rainfall erosion index can be expressed as a function of rainfall intensity alone. The rainfall erosion index, R, is computed from rainfall records of individual storms and summed over a given time interval to obtain the cumulative R value to be used in the soil-loss equation. The annual R factors for approximately 2,000 locations in the United States have been summarized in the form of "iso-erodent" maps by Wischmeier and Smith (Reference 136). Figure 45 shows an example of such iso-erodent maps. This reference handbood provides data and figures for estimating average monthly soil loss in tons per ac per yr from cropland east of the Rocky Mountains. It also lists 5, 20, and 50 percent probability values of the erosion index and the expected magnitudes of the single-storm erosion index values for return periods of 1, 2, 5, 10 and 20 years

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without specifying the storm duration periods. While the Handbook was prepared for use in agricultural areas, the methodology and data can be used for estimating erosion in urban areas and at construction sites anywhere.

The problems of estimating erosion soil loss in the West, however, was more difficult since there was no ready source similar to Reference 136 for areas west of the Rocky Mountains available when the studies for this report were begun in July 1972. In late September 1972, the SCS provided a copy of their Technical Release No.51 (Reference 105) which included a tentative guide for application of the universal soil loss equation to the western area. A curve was presented which enabled the annual rainfall erosion index to be graphically estimated from the 2-yr frequency 6-hr rainfall at any particular location. This curve proved to be a valuable checkpoint, on the relationship between single-storm erosion indices and annual erosion indices. It was desired, however, to develop a methodology which would tie together both the eastern and the western data. Because rainfall energy is the principal criterion for the rainfall erosion index portion of the soil-loss equation, an analysis of this aspect was undertaken.

A. Rainfall Erosion Index for Individual Storm Rainfall

Wischmeier and Smith (135) presented an equation describing rainfall kinetic energy as a function of rainfall intensity. This relationship is given in Equation (3). In order to compute the total kinetic energy of a given storm they used the information available from recording raingage charts. A tabular record of rainfall intensities, with the amount of rain falling at each of the successive intensity increments was obtained from the recorder chart. The kinetic energy for each intensity increment was calculated using Equation (3) and the result was multiplied by the depth of rain falling at that rate. These partial products were accumulated to obtain the total energy value for the storm.

Rainfall distribution with respect to time was analyzed using the storm rainfall distribution curves presented by the Soil Conservation Service Technical Paper No. 149 (Reference 104). Typical rainfall patterns from two major regions were identified and time distributions for each are presented in Figure 46. Type I is representative of Hawaii, Alaska, and the coastal side of the Sierra Nevada and Cascade Mountains in California, Oregon, and Washington. Type II distribution is representative of the rest of the United States, Puerto Rico and the Virgin Islands. The type I and II distribution patterns are based on the generalized rainfall depth-duration relationships given in U.S. Weather Bureau Technical Papers. Based on the method used and prescribed by Wischmeier and Smith (Reference 131) and the generalized rainfall distribution curves shown on Figure 46, a solution for kinetic energy and the erosion index for an individual storm of 24-hr duration was calculated with the aid of graphical approximations, for various values of total rainfall, both for Type I and Type II regions. See Appendix B, Part 2, for details. A plot of the calculated data produced the following equations for an individual 24-hr duration storm erosion index.

$$\text{Type I:} \quad \frac{EI}{100} = 2.176 \; (P_{24\ hr})^{2.2} \qquad (4)$$

$$\text{Type II:} \quad \frac{EI}{100} = 4.365 \; (P_{24\ hr})^{2.2} \qquad (5)$$

Assuming that the distribution of rainfall against time (as given for the 24-hr duration and expressed in dimensionless form both for time and accumulated rainfall) will hold true for any durations, then the erosion index values can be calculated for various durations and rainfall depths. Graphical analysis of the calculated data, yielded the following generalized relationships.

Individual Storm Erosion Index:

$$\text{Type I:} \quad \frac{EI}{100} \text{ (30 min max)} = \frac{15P^{2.2}}{H_r^{0.6065}} \qquad (6)$$

$$\text{Type II:} \quad \frac{EI}{100} \text{ (30 min max)} = 19.25 \, \frac{P^{2.2}}{H_r^{0.4672}} \qquad (7)$$

where: P = storm rainfall in inches

H_r = duration of rainstorm in hours

Figures 50 and 51 present the above two equation in graphic form. This method of presentation of individual storm erosion index is helpful in the comparison and evaluation of the erosion index of rainfalls of various depths and durations.

B. Estimation of Average Annual Erosion Index

With the relationships of intensity, depth, and duration of rainstorms presented in USWB TP No. 24 (Reference 123) the erosion index values for rainstorms of different duration but of equal frequency could be easily plotted on a log-log graph such as in Figures 50 and 51. For a hypothetical station in the west (i.e., in Zone I, which represents an area in which Type I distribution of rainstorm takes place) the calculated values of erosion index for 2-yr return periods (i.e., 50 percent probability) were plotted for rainstorms of 30 min and up to 24-hr duration. These plots indicated that for Type I rainstorms the individual erosion index values for 24-hr duration was 9 percent more than that of the 6-hr storm index while for the Type II rainstorms the 24-hr erosion index was only 6.5 percent more than that of the 6-hr index. Since the variation in the erosion index values for different rainstorm durations of equal frequency was not very large, it was argued that the equation for the individual erosion index could be converted into one for annual erosion index if one could determine first the most common or frequent rainfall duration period. The SCS Field Engineering Manual (Reference 100) presents a graph indicating the relationship between effective duration (i.e., the most frequently occurring phenomena) and average annual precipitation.

The reasoning that a given rainstorm duration erosion index formula could be adapted to yield an average annual erosion index is strengthened by the fact that the sediment yield caused by large storms (with return period greater than 2 yr) in 72 small watersheds in 17 States is 20.4 percent of the total average annual sediment yield, on the average. For moderate storms (with return period between 1 and 2 years) the sediment yield, on the average, is 10.6 percent of the total average annual yield. Also, for most watersheds, more than one-half of the soil losses are attributable to the smaller storms that occur more than once a year on the whole (Piest, Reference 73). This conclusion is corraborated by Wischmeier (Reference 131), who concluded that the bulk of the soil loss can be attributed to the more frequent storms that have at least a 50 percent chance of occurrence in any given year. Diseker and Sheridan (Reference 25) state that on roadbanks, the five largest storms produce, on the average, 71.9 percent of the total annual sediment yield. The largest storm in the group produces an average of 31.3 percent of the total annual sediment.

Such conclusions strengthen the probability that a direct empirical relationship can be developed between a given duration rainstorm of a 2-yr frequency and annual erosion index. Wischmeier (Reference 131) asserted that when the data from the original 181 locations were analyzed, a three-factor product (average annual rainfall times the 2-yr, 1-hr intensity times the 2-yr, 24-hr intensity) explained 95.4 percent of the total variation in erosion index values. This correlation technique was used by Wischmeier to estimate the erosion index for 1,700 additional locations evenly distributed in 37 States. The 2-yr, 1-hr and 24-hr rainfall amounts were taken by Wischmeier from the USWB Technical Paper No. 29, and from similar but unpublished maps. Average annual rainfall data for each of these locations were secured from USWB Local Climatological Data. The estimated erosion index values for these 1,700 locations were then mapped, along with those derived directly from the 181 locations with 22-yr basic rainfall records. The resultant map is the iso-erodent map presented in USDA Handbook No. 282 (Reference 136) and reproduced in Figure 45.

Analysis of the USWB proposed rainfall depth-duration diagram Figure 2 in USWB Technical Paper No. 40 (Reference 124) yielded the very interesting and significant result that the 6-hr rainfall depth is the average of the 1-hr and 24-hr rainfall for any given location in the United States. This finding proved very encouraging, since the product of 2-yr 1-hr and 2-yr 24-hr could be replaced with the 2-yr 6-hr duration raised to the second power times a constant (the USWB Technical Paper No. 40 states that in using their Figure 2 the depth of rainfall for various duration, but all of the same frequency, will plot as a straight line, and as a corollary, that the $\frac{P_1}{P_{24}}$ for a small region can be considered constant.)

The erosion index for a Type II individual storm rainfall of 6-hr duration is equal to $8.25P^{2.2}$ where P is the 6-hr rainfall depth.

Close examination of the pattern of the 2-yr 6-hr rainfall map prepared by the USWB Technical Paper No. 40 and comparison with the pattern of average annual values of rainfall factor, R, (otherwise known as the Iso-Erodent Map) which is presented as Figure 1 in USDA Handbook No. 282 reveals that there exists a very strong correlation between the two maps. After estimating the corresponding individual storm rainfall erosion indices, the mean ratio of average annual erosion index and 2-yr 6-hr individual storm rainfall erosion index, is calculated at 3.265. This means that the average annual rainfall erosion index is equal to 3.265. times the 2-yr 6-hr individual storm rainfall erosion index. Thus, for Type II Storms:

$$\text{Average Annual Rainfall Erosion Index} = 8.25 \times 3.265 \times P^{2.2}$$

$$= 27P^{2.2} \qquad (8)$$

Using the values of 2-yr 6-hr rainfall, shown on Figure 6 from the USWB Technical Report #40, annual erosion index values were calculated and smoothed iso-erodent lines were drawn onto the USWB 2-yr 6-hr rainfall map. The results on Figure 49 as compared to the annual iso-erodent map shown in Figure 45, are almost identical.

This is a strong evidence for the applicability of the SCS rainfall distribution curve for rainfall erosion energy estimating purposes, and shows that the estimation of average annual erosion index could be condensed into a simple formula. This formula fits the data for areas east of the Rocky Mountains, which are considered to receive Type II rainstorms only. It is felt that similar reasoning or approach could be applied to Type I rainstorm areas of the Pacific Coast west of the Rocky Mountains.

The 6-hr individual rainstorm erosion index for Type I distribution is found to be $5.07P^{2.2}$. Multiplying this by the factor of 3.265, the following equation is obtained for Type I storm rainfall distributions.

$$\text{Type I Storms: Average Annual Rainfall Erosion Index} = 16.55P^{2.2} \qquad (9)$$

As an independent check to confirm the validity of the above relationship the average annual erosion index for Red Bluff and San Luis Obispo were calculated from the 2-yr 6-hr rainfall (1.75 and 1.60 in. respectively from USWB TP No. 40). This resulted in values of 57 and 46 respectively. Whereas Table 11 of Handbook No. 282 lists the erosion index values of 50% probability for the same locations as 54 and 43 respectively. In addition, Table 12 of the same handbook lists the expected magnitude of single-storm erosion index normally exceeded once in 2 years as 21 and 15 respectively. The 2-yr 6-hr storm erosion indexes are estimated from the formula

$\frac{EI}{100} = 5.07P^{2.2}$ at 17.5 and 14.3, respectively.

(Using the 2-yr 24-hr rainfall single-storm erosion index will be estimated for 2.8- and 2.4- in. rainfall at 20.5 and 15, respectively.) These two independent checks to corroborate the validity and the accuracy of the empirical formulas were developed in the course of this study.

2. SOIL CONSERVATION SERVICE TECHNICAL RELEASE #51

In September 1972, the U.S. Soil Conservation Service issued Technical Release No. 51 (Reference 105), entitled "Procedure for Computing Sheet and Rill Erosion on Project Areas". Use of the universal soil loss equation was extended by provision of data for additional plant cover factor (C) for permanent pasturland, rangeland, woodland, and idle land.

Technical Release No. 51 also states specifically that "EI factors have not been evaluated from actual rainfall data in the States comprising the SCS West Region and to some degree in the Caribbean Area". It goes on to state that the ARS Soil Loss and Runoff Laboratory has provided iterim EI and R data that may be used where rainstorms of significant kinetic energies and intensities are common. The interim EI or R factors are presented in graphic form, whereby a direct reading may be obtained from this graph after the 2-yr, 6-hr rainfall has been determined for the area involved.

Examination of the values of EI or R factors corresponding to given magnitudes of 2-yr 6-hr rainfall indicate that the curve presented in their Figure 1 of TR No. 51 represented Type II rainfall distribution. In fact, the curve proved to give results identical to those obtained from Equation 8, derived by Engineering-Science, Inc., (ES), from the SCS Type II Storm S-curve and the rainfall energy equation of Wischmeier, as has been explained previously. Hence, the curve and the equation are applicable to all areas in the United States where Type II storms prevail.

On the other hand, the curve gives results too high for Type I storm areas, according to Equation 9, developed by ES on the same basis of kinetic energy and storm rainfall intensities. The ES equation Type I values are about 61 percent of the Type II values. Curves for both storm types are shown in Figure 47. The EI or R values suggested by SCS TR No. 51 will result in EI or R values on the conservative side. This in itself is acceptable if only the relative magnitude of the erosion index were desired. However, for design purposes, especially for cost considerations, and for estimation of K-factors from the universal soil loss equation, a 60 percent discrepancy cannot be tolerated.

3. SUMMARY PROCEDURES FOR ESTIMATION OF RAINFALL EROSION INDEX

A. Example 1 Rainfall Erosion Index for a 2-yr 6-hr Storm

This can be considered a typical "average" storm, since it can be expected to occur 50 percent of the time, and the 6-hr duration has been found by SCS to be the most frequently occurring storm length.

(1) Locate the area under study on a chart in USWB TP No. 40 (or similar publication) similar to Figure 48.

(2) Determine the value of the 2-yr 6-hr rainfall from the preceding chart.

(3) Check as to the zone (Zone I or Zone II) in which the area under study is located.

(4) The storm erosion index can be estimated by either of the three methods listed below.

(a) Use of the following formulas:

Type I: $\frac{EI}{100} = 5.07P^{2.2}$

Type II: $\frac{EI}{100} = 8.25P^{2.2}$ or,

(b) Use the graph in Figure 50, or Figure 51 to arrive at the erosion index, using the 6-hr duration line or,

(c) Use the applicable Type I or Type II curve in Figure 47. Enter the graph at the appropriate value of the 2-yr 6-hr rainfall and read the corresponding average annual rainfall erosion index. To obtain the 2-yr 6-hr erosion index, divide the annual erosion index by 3.265.

Examples:

Walnut Creek Drainage Basin, California. (Zone I)

From USWB TP 40, the 2-yr 6-hr rainfall is given at 1.5 in. Therefore, using steps 4 (a), (b), or (c) the erosion index is found to be:

$$\frac{EI}{100} = 5.07\ (1.5)^{2.2} = 5.07 \times 2.44 = 12.4$$

Estimated erosion index from Figure 50 = 12

Annual erosion index from Figure 47 = 40

Estimated erosion index = $\frac{40}{3.265}$ = 12.25

Occoquan Drainage Basin, Virginia (Zone II)

From USWB TP 40, the 2-yr 6-hr rainfall is given as 2.55 in. Using steps 4 (a), (b), or (c), the erosion index is found to be:

$$\frac{EI}{100} = 8.25\ (2.55)^{2.2} = 8.25 \times 7.85 = 65.0$$

Estimated erosion index from Figure 51 = 66.0

Annual erosion index from Figure 47 = 210*

Estimated erosion index = $\frac{210}{3.265}$ = 64.3

*Note that the official value for annual erosion as listed in USDA Handbook No. 282 is 200.

B. Example II Rainfall Erosion Index for Storm of Any Duration Up to and Including 24-Hour for 2-Year Frequency

The procedure is the same as for Example I, except that the chart used from USWB TP 40 will be the one for the storm frequency and duration desired. Step 4 (c) cannot be used; only alternative 4 (a) and 4 (b) are applicable, but modified accordingly as follows:

(a) Use one of the following formulas:

$$\text{Type I}: \quad \frac{EI}{100} = \frac{15 \quad P^{2.2}}{H_r^{0.6065}}$$

$$\text{Type II}: \quad \frac{EI}{100} = 19.25 \frac{P^{2.2}}{H_r^{0.4672}}$$

(b) Use the graph in Figure 50 or Figure 51 to arrive at the erosion index using the appropriate depth of rainstorm and duration hour line.

Example:

Determine the erosion index for a 24-hr storm with a 2-yr frequency in the vicinity of Occoquan. USWB TP 40 shows depth of precipitation for such a storm to be 3.40 in. Area is in Zone II.

(a) $$\frac{EI}{100} = 19.25 \frac{(3.40)^{2.2}}{24^{0.4672}} = \frac{19.25 \times 15}{4.42} = 66$$

(b) Estimated erosion index from Figure 51 = 65

C. Example III Average Annual Rainfall Erosion Index

(1) Locate the area under study in a chart in USWB TP 40 (or similar publication).

(2) Determine the value of 6-hr rainfall for the 2-yr frequency.

(3) Check as to the Zone in which the area is located.

(4) Calculate the annual erosion index by one of the following equations:

$$\text{Type I} \ : \ \text{Average Annual } \frac{EI}{100} = 16.55\ P^{2.2}$$

$$\text{Type II:} \ \text{Average Annual } \frac{EI}{100} = 27\ P^{2.2}$$

Example:

Determine the 2-yr frequency annual erosion index for the Walnut Creek, California and Occoquan River, Virginia, areas.

Walnut Creek: Average Annual Erosion Index = $16.55\ (1.5)^{2.2} = 40$

Occoquan River: Average Annual Erosibn Index = $27\ (2.55)^{2.2} = 210$

APPENDIX B

PART 2 - DERIVATION OF EQUATIONS FOR EROSION INDEX $\frac{EI}{100}$ FROM TYPE I AND TYPE II STORM DISTRIBUTION CURVES

1. 24-HOUR DURATION STORM EROSION INDEX

The SCS Type I and Type II S-curves (Figure 46) were first divided into ten parts so that an average slope for each increment could reasonably represent the rainfall intensity during that increment of time. Then the kinetic energy was calculated, using Equation (3), for each increment. Each of these partial kinetic energies were multiplied by the corresponding partial rainfall, and these products were summed to arrive at the total Kinetic Energy (E) of the storm. This value was then multiplied by the maximum 30-min intensity and divided by 100 to arrive at the storm erosion index. A sample calculation is attached for further clarification.

2. STORM EROSION INDEX FOR RAINFALL OF LESS THAN 24-HOUR DURATION

In order to calculate the erosion index for storms of duration less than 24 hr, the following approach was adopted:

A. Take 1/2, 1/3, 1/4, 1/6, 1/8, and 1/12 of 24 hr to give 12 hr, 8 hr, 6 hr, 4 hr, 3 hr, and 2 hr durations. By definition, intensity is rainfall depth divided by time interval, i.e.,

$i = \frac{\Delta P}{\Delta t}$, For three durations, intensities are computed:

12 hr $$i_{12} = \frac{\Delta P}{\frac{\Delta t}{2}} = 2 \left(\frac{\Delta P}{\Delta t}\right) = 2 \left(i_{24}\right)$$

8 hr $$i_{8} = \frac{\Delta P}{\frac{\Delta t}{3}} = 3 \left(\frac{\Delta P}{\Delta t}\right) = 3 \left(i_{24}\right)$$

6 hr $$i_{6} = \frac{\Delta P}{\frac{\Delta t}{4}} = 4 \left(\frac{\Delta P}{\Delta t}\right) = 4 \left(i_{24}\right)$$

Thus, the average intensities to be used for a 1-in rainstorm in 12 hr are those of an equivalent 2-in rainstorm of 24-hr.

The intensity increment values determine the partial kinetic energy, but the total weighted kinetic energy of a rainstorm is equal to the summation of the products of the partial kinetic energy times partial rainfall. Thus, the partial kinetic energy during an increment of a rainfall of 2-in in 24-hr times the corresponding partial rainfall increments of 1-in gives the result that a 1-in rainfall in 12-hr has a total kinetic energy of only half that of a 2-in rainfall in 24-hr.

Type I

Graphical solution for calculating kinetic energy of a 24-hour storm.

Divide the S-curve into 10 portions as follows:

Interval	Time	t	Px/P_{24}	$\Delta Px/P_{24}$	Intensity $\frac{\frac{\Delta Px}{P_{24}}}{t}$
1	0-6 hrs	6	00.00-0.1300	0.130	0.0217
2	6-8	2	00.13-0.195	0.065	0.0325
3	8-9	1	0.195-0.255	0.060	0.0600
4	9-9.55	0.55	0.255-0.315	0.060	0.1090
5	9.55-10.05	0.50	0.315-0.525	0.210	0.4200
6	10.05-10.60	0.55	0.525-0.595	0.070	0.1270
7	10.60-11.60	1	0.595-0.600	0.065	0.0650
8	11.60-14.00	2.4	0.660-0.768	0.108	0.0450
9	14.00-17.00	3	0.768-0.855	0.087	0.0290
10	17.00-24.00	7	0.855-1.000	0.145	0.0207

Interval	Intensity (i P=1)	Kinetic Energy (ε)	Partial Rainfall (Px)	εPx	ΣεPx=E_1	E_1xI_1÷100
1	0.0217	364	0.130	47.32	47.32	100
2	0.0325	422	0.065	27.43	74.75	
3	0.0600	512	0.060	30.72	105.47	
4	0.1090	677	0.060	40.62	146.09	
5 I max	0.4200	791	0.210	166.11	312.20	
6	0.1270	619	0.070	43.33	355.53	
7	0.0650	523	0.065	34.00	389.53	
8	0.0450	469	0.108	50.65	430.18	
9	0.0290	383	0.087	33.32	463.50	$\frac{515.41x0.420}{100}$ = 2.16
10	0.0207	358	0.145	51.91	515.41	

Interval	Intensity (i P=2)	Kinetic Energy (ε)	Partial Rainfall (Px)	εPx	$\Sigma\varepsilon Px = E$	$E_2 x I_2 \div 100$
1	0.0434	464	0.260	120.40	120.40	
2	0.0650	523	0.130	68.00	188.40	
3	0.1200	611	0.120	73.50	261.90	
4	0.2180	697	0.120	83.80	345.70	
5	I max = 0.8400	891	0.420	374.00	719.70	
6	0.2540	719	0.140	100.60	820.30	
7	0.1300	623	0.130	81.20	901.50	
8	0.0900	570	0.216	123.00	1024.50	
9	0.0580	507	0.174	88.50	1113.00	$\frac{1.245.40 x 0.84}{100} = 10.46$
10	0.0414	457	0.290	132.40	1245.40	

Interval	Intensity (i P=5)	Kinetic Energy (ε)	Partial Rainfall (Px)	εPx	$\Sigma\varepsilon Px = E$	$E_5 x I_5 \div 100$
1	0.0085	609	0.650	395.00	395.00	
2	0.1625	655	0.325	213.00	608.00	
3	0.3000	743	0.300	223.00	831.00	
4	0.5450	829	0.300	249.00	1080.00	
5	I max = 2.1000	1023	1.050	1073.00	2153.00	
6	0.6350	851	0.350	298.00	2451.00	
7	0.3250	755	0.325	245.00	2696.00	
8	0.2250	701	0.540	378.00	3074.00	
9	0.1450	638	0.435	277.00	3351.00	$\frac{3,779 x 2.1}{100} = 79.8$
10	0.1035	590	0.725	428.00	3779.00	

Interval	Intensity (i P=10)	Kinetic Energy (ε)	Partial Rainfall (Px)	εPx	$\Sigma\varepsilon Px = E$	$E_{10} x I_{10} \div 100$
1	0.2170	696	1.300	905.00	905.00	
2	0.3250	755	0.650	491.00	1396.00	
3	0.6000	843	0.600	506.00	1902.00	
4	1.0900	928	0.600	556.00	2458.00	
5	I max = 4.2000	1122	2.100	2355.00	4813.00	
6	1.2700	950	0.700	665.00	5478.00	
7	0.6500	854	0.650	555.00	6033.00	
8	0.4500	801	1.080	865.00	6898.00	
9	0.2900	738	0.870	642.00	7540.00	$\frac{8,540 x 4.2}{100} = 358.7$
10	0.2070	690	1.450	1000.00	8540.00	

B. On the other hand, since the time stipulated for maximum intensity is fixed at 30 min, it is logical to reason that as the time scale is reduced from 24 to 12, 8, 6, 4, 3 and 2 hr, that the 30-min time interval for these shorter storms will be the equivalent of 60, 90, 120, 180, 240 and 360 min. of the 24-hr duration curve. This of course means that the corresponding intensities (30-min max) have to be recalculated. The calculated maximum 30-min intensities are as follows for a 1-in rainfall each for Type I distribution.

24 hr	0.420
12 hr	0.540
8 hr	0.660
6 hr	0.730
4 hr	0.866
3 hr	0.970
2 hr	1.244
1 hr	1.550
1/2 hr	2.000

C. The mathematical calculations that follow from the above deductions are as follows.

(1) Erosion Index (Type I) (assuming same values for I max 30 min as that for the equivalent 24-hr duration)

$$\frac{EI}{100} = 2.176\ (P_{24})^{2.2} \text{...............24-hr duration}$$

$$\frac{EI}{100} = 1/2\ [(2.176)\ (2\ P_{12})^{2.2}] \text{.....12-hr duration}$$

$$\frac{EI}{100} = 1/3\ [(2.176)\ (3\ P_8)^{2.2}] \text{...... 8-hr duration}$$

$$\frac{EI}{100} = 1/4\ [(2.176)\ (4\ P_6)^{2.2}] \text{...... 6-hr duration}$$

The above relationship can be put in a more generalized form as follows.

$$\frac{EI}{100} = \frac{1}{n}\ [(2.176)\ (n\ Px)^{2.2}] = 2.176\ (n)^{1.2}\ (Px)^{2.2}$$

where: $n = \frac{24}{H_r}$ and: x = duration of storm in hours

Substituting for n we get:

$$\frac{EI}{100} = 2.176\left(\frac{24}{H_r}\right)^{1.2}(Px)^{2.2}$$

where: $H_r = x$, and Px = rainfall occurring during H_r hours

(2) Erosion Index (Type I) (taking into consideration the fact that actual 30-min maximum intensity will be as listed in B).

The reduction in the intensity was calculated for each duration time and graphical analysis yielded the following equation for the reduction coefficient for Type I distribution.

$$N = \left(\frac{24}{H_r}\right)^{-0.5935}$$

(3) Therfore, the actual erosion index is equal to the product of the two equations derived in (1) and (2) preceding as follows:

$$\frac{EI}{100} = \left[2.176\left(\frac{24}{H_r}\right)^{1.2}(Px)^{2.2}\right]\left[\left(\frac{24}{H_r}\right)^{-0.5935}\right]$$

$$= 2.176\left(\frac{24}{H_r}\right)^{0.6065}(Px)^{2.2}$$

$$= 2.17\,(24)^{0.6065}\,\frac{(Px)^{2.2}}{H_r^{\,0.6065}}$$

$$= 2.176 \times 6.88\,\frac{(Px)^{2.2}}{H_r^{\,0.6065}}$$

$$= 15\,\frac{Px^{2.2}}{H_r^{\,0.6065}}$$

(Type I Storm)

Similarly, the following equation can be derived:

$$\frac{EI}{100} = 19.25\,\frac{Px^{2.2}}{H_r^{\,0.4672}}$$

(Type II Storm)

APPENDIX C

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